The Journal of Bone and Joint Surgery

The Official Publication of
The American Orthopaedic Association
The British Orthopaedic Association
The American Academy of Orthopaedic Surgeons
The Australian Orthopaedic Association
The Canadian Orthopaedic Association
American Society for Surgery of the Hand
New Zealand Orthopaedic Association
South African Orthopaedic Association

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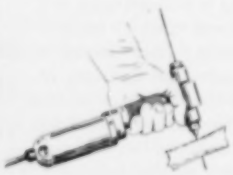

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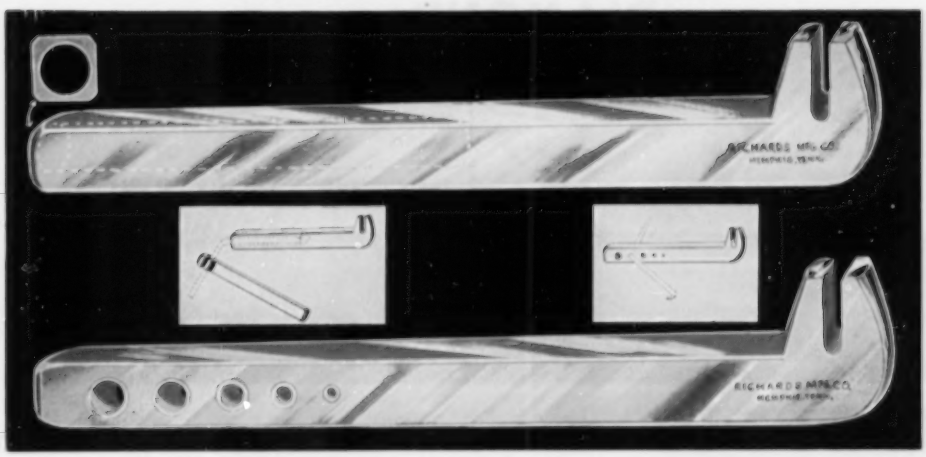

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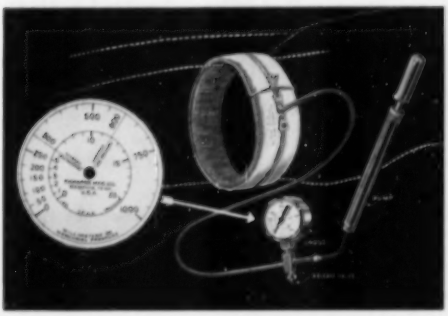

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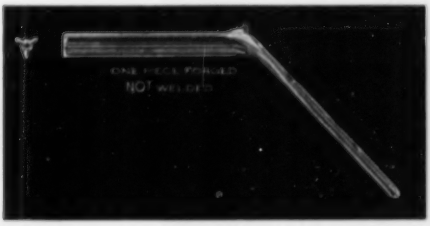

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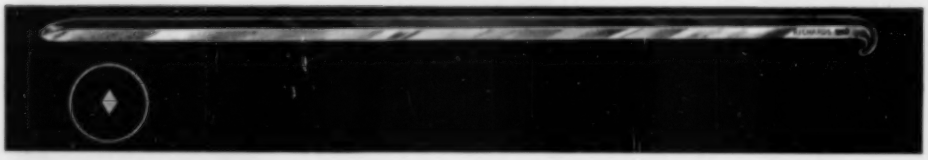

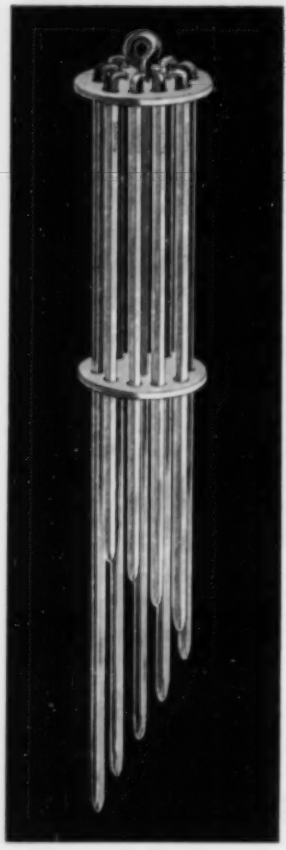

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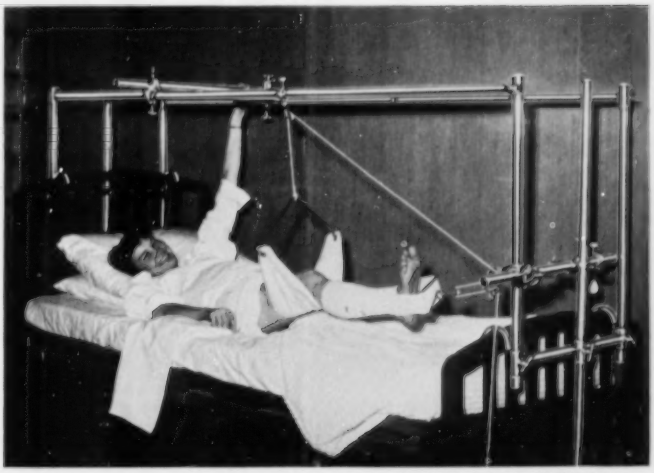

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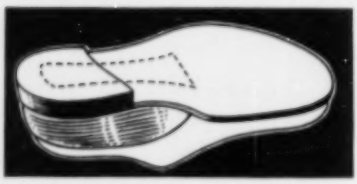

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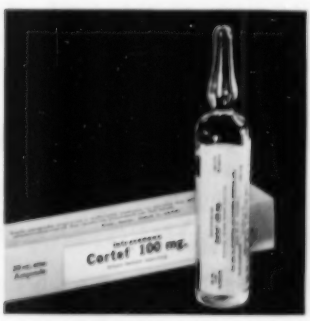

Vitallium® TROCHANTERIC NAIL-PLATES

NEUFELD TYPE

NOW AVAILABLE IN RESPONSE TO THE DEMAND OF THE MANY SURGEONS WHO ASKED FOR THEM

Like all Vitallium appliances, Vitallium Trochanteric Nail-Plates are completely inert in the human body. Their strength and engineered design permits contouring at the operative site for close adaptation to the bone. They have the characteristic "satin finish" of Vitallium appliances, reducing undesirable glare during the operation.

Effective fixation with Vitallium Neufeld-type nail-plates results in a feeling of security, better patient morale and shorter hospital confinement.

★ ★

Together with the Vitallium Jewett and McLaughlin-type inter-trochanteric appliances, the various Vitallium hip nails and screws, the Vitallium ready-made hip prostheses and the Bosworth-type splines, the addition of this Neufeld-type trochanteric nail-plate to the ever-increasing line of Vitallium surgical appliances provides the surgeon with a wider choice of fixation and repair appliances for the upper femoral region than is available from any other source.

★ ★

YOU CAN RELY UPON VITALLIUM SURGICAL APPLIANCES. They are made of a homogeneous, uniform alloy, completely passive, compatible and friendly to human bone and tissue.

INDICATED USES ABOUT THE HIP

1. Sub-capital fractures
2. Trans-cervical fractures
3. Per-trochanteric fractures
4. Inter-trochanteric fractures
5. Sub-trochanteric fractures
6. Oblique or spiral fractures
7. High femoral osteotomies

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ORDER THROUGH YOUR SURGICAL DEALER

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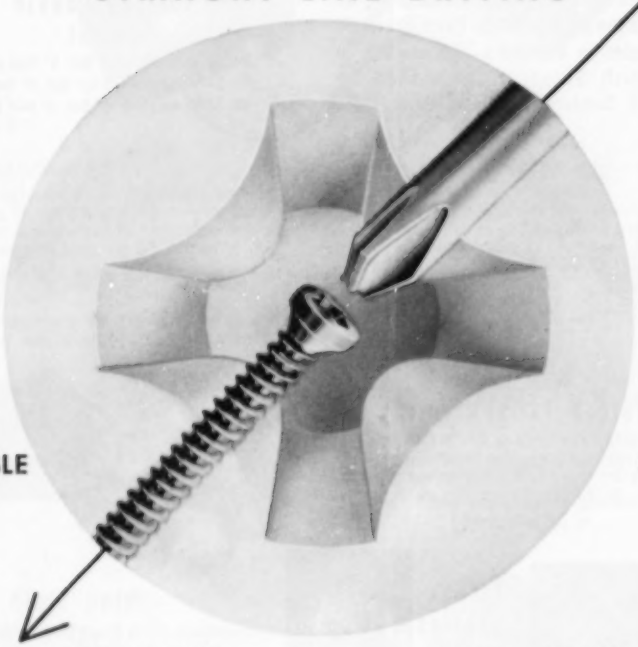
Vitallium®

PHILLIPS RECESSED HEAD SCREW

- SUPERIOR HEAD STRENGTH
- STRAIGHT LINE DRIVING



- STRONG
- INERT
- COMPATIBLE
- PASSIVE
- RUGGED DRIVER
- SELF CENTERING
- NO DRIVER SLIPPAGE

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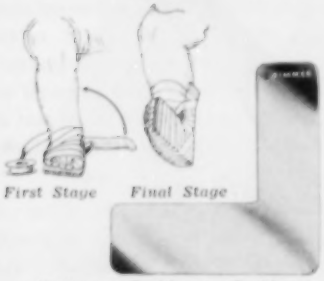
Denis Browne Splints by *Zimmer*

These splints have been made according to the design and measurements supplied by Mr. Denis Browne, F. R. C. S. England, Surgeon to the hospital for Sick Children, Great Ormond St., London. For details of diagnosis, prognosis and treatment, we refer the surgeon to Mr. Denis Browne's chapter in Maingot's "Techniques in British Surgery," published by W. D. Sanders Co., Philadelphia, 1950.

Talipes Hobble Splint

No. 577A, large, 6½" bar, 5" foot plate.
No. 577B, medium, 5½" bar, 4" foot plate.
No. 577C, small, 4½" bar, 3" foot plate.



Valgus Talipes Splint

No. 578A, large, right or left, 5" foot plate.
No. 578B, medium, right or left, 4" foot plate.
No. 578C, small, right or left, 3" foot plate.
(In ordering, please specify whether right or left is required.)

Infant Scoliosis Splint

No 698

This light, aluminum frame holds the child with the spine in the reverse curve from the one with which it was born, but otherwise allows free movement. It has these advantages over the usual plaster of paris bed or shell:

Congenital-Dislocation-of-Hip Splint

No. 780A, large, adjustable frame, 13½" to 16¼" (outside measurements).
No. 780B, medium, adjustable frame, 11¾" to 13½".
No. 780C, small, adjustable frame, 9¼" to 11½".
Splint applied posteriorly with dotted lines showing range of movement permitted.

Zimmer

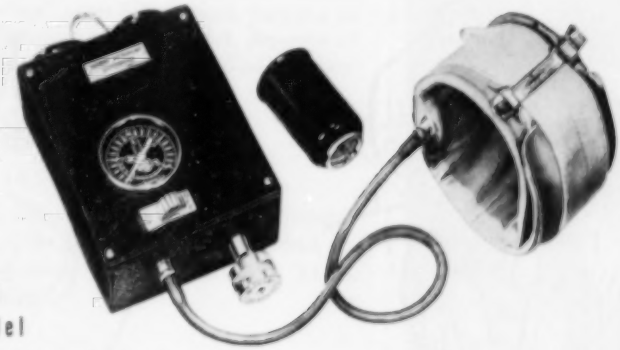
ZIMMER MANUFACTURING CO. WARSAW, IND.

In Canada Available through selected surgical supply dealers or through our Agents, Fisher & Burpe, Ltd.

Look for the trademark

Zimmer presents the ROBBINS

Automatic Regulated TOURNIQUET . . .



No. 975
$100.00
as shown

Operating Room Model

Automatic quick inflation of cuff.

The pressure is governed by the control knob to desired setting on the dial and is absolutely maintained constant until changed by turning the control knob or released by pushing the ON-OFF valve.

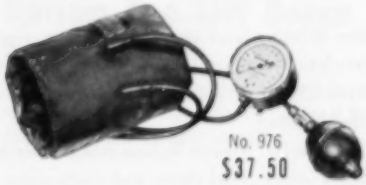
For the first time the pressure may be varied at will during surgery.

Reliable in maintaining set pressure. No danger of loss of pressure, even if Freon container is removed or changed. No need constantly to watch accurate dial.

Safe Freon used is non-toxic and non-inflammable. Slow release is assured to minimize shock from too sudden drop in blood pressure.

Available for children.

Special children's cuffs which are available, plus the complete control of pressure, make this tourniquet of great value in pediatrics.



No. 976
$37.50
as shown

Robbins Blood Pressure Unit

An entirely new type of cuff, a new gauge and a new method of finger-tip bulb control combine to speed and simplify the taking of blood pressure by you, by your assistant and even by your patient.

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$45.00
as shown

Field Unit

1 Convenient cloth carrying pouch with instruction tag.
2 Inflatable cuff, 3" wide, covered with dirt-resistant, easily cleaned, woven fabric.
3 Cloth strap, 23" long, for wrapping cuff and itself aroung limb.
4 Metal fastener with three teeth to hold strap in position under pressure.
5 Metal fastener of strap to cuff.
6 Pressure release valve.
7 Body of instrument containing regulator mechanism.
8 Off-On button.
9 Cartridge container.
10 Standard CO_2 gas cartridge.

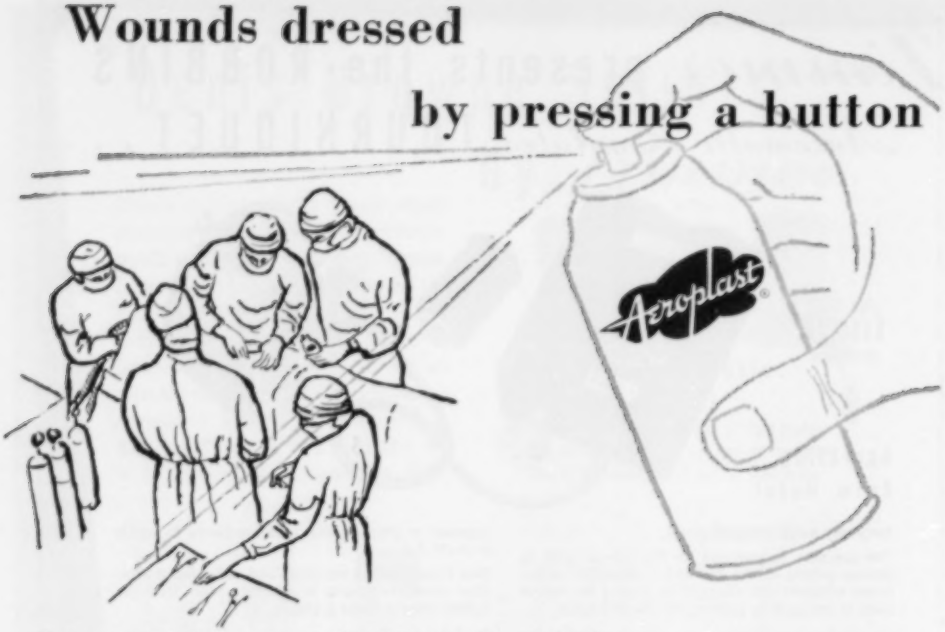
ZIMMER MANUFACTURING CO. WARSAW, IND.

Zimmer

In Canada Available through selected surgical supply dealers or through our Agents, Fisher & Burpe, Ltd.

ON DISPLAY AT AMERICAN COLLEGE OF SURGEON'S CONGRESS—BOOTHS 402-404

Wounds dressed by pressing a button



Sprayed directly onto the lesion from a self-contained aerosol "bomb", AEROPLAST replaces conventional gauze and tape dressings in all routine surgical uses.

AEROPLAST forms a transparent protective dressing over any body surface, regardless of contour, yet does not restrict circulation, respiration, or movement. Transparency, a unique advantage, permits critical evaluation of healing progress at a glance without disturbing or removing the dressing.

Aeroplast dressings are impermeable to bacteria. Aseptic lesions remain sterile as long as the dressings are allowed to remain intact. Vital fluids and electrolytes are sealed in.

Aeroplast dressings are strong and flexible; they withstand washing, friction, and the stress of motion. They are non-toxic, non-sensitizing, and non-allergenic. Easy to remove after a sufficient period for complete "setting", Aeroplast dressings are simply peeled off.

Major operative procedures such as laparotomies, thoracotomies, ileostomies, skin graft donor sites, openly reduced fractures, etc., as well as burns, excoriation, abrasions, and lacerations, are typical of the broad variety of cases in which Aeroplast has been used to advantage as the sole dressing agent.*

Supplied in 6 oz. aerosol-type dispensers through your prescription pharmacy or surgical dealer.

For reprints and literature write to: **AEROPLAST CORPORATION**
422 Dellrose Avenue, Dayton 3, Ohio

* Choy, D. S. J.: Clinical trials of a new plastic dressing for burns and surgical wounds. A.M.A. Arch. Surg. 68:33-43 (Jan.) 1954

Denis Browne Splint

Part No. 140

Standard type Denis Browne Splint. New style nut will not tear bed sheets. Easily adjustable locking positions, which cannot be stripped. Degrees on foot plate enable doctor to check progress of patient. Manufactured from 24 st. aluminum alloy.

Denis Browne Splint

Part No. 141

Swivel type Denis Browne Splint. Easily adjustable to any angle or degree and can be locked securely in position. Manufactured from 24 st. aluminum alloy.

Spring Toe Lift Brace

Part No. 149

Spring Toe lift head on lower side connected with stirrup allows bending of brace more closely to the ankle. Lower section forged steel, upper section ⅛″ x ⅝″ steel.

Spring Toe Lift Brace

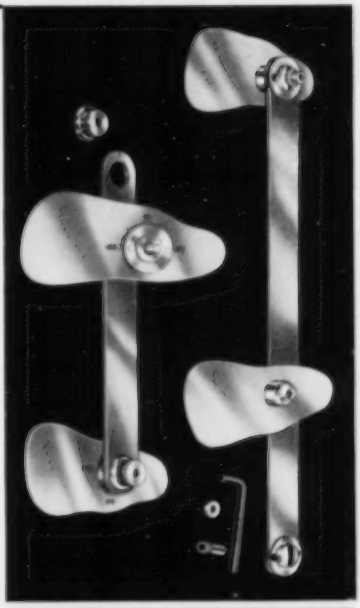
Part No. 150

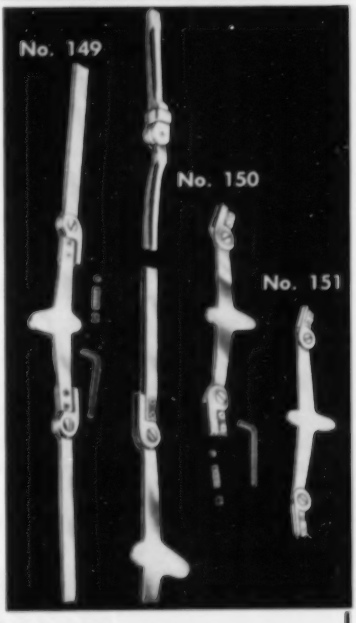
Spring Toe Lift Brace to be used in combination with long leg braces. Plain or plated finish. Manufactured from forged steel.

Free Ankle Joint

Part No. 151

Free Ankle Joint with 90 degree stop, designed for use with long leg braces. Plain or plated finish. Manufactured from forged steel.





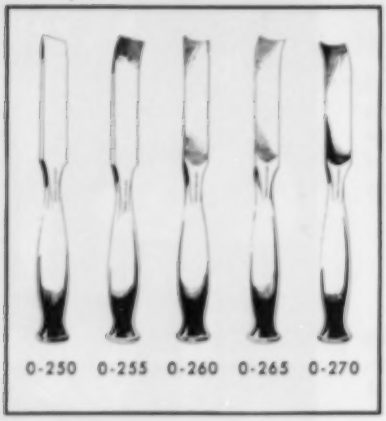
The **United States Manufacturing Company** is a manufacturer and supplier of prefabricated steel and aluminum ball bearing braces and sundry items. The use of prefabricated braces saves fitter's time and costs less.

For further information wire or write:

United States Manufacturing Company

3453 Glendale Boulevard, *Dept. BJ* **Los Angeles 39, California**

SMITH-PETERSEN OSTEOTOMES and GOUGES



0-250 0-255 0-260 0-265 0-270

0-250 SMITH-PETERSEN OSTEOTOME—straight, 8", sizes ¼", ⅜", ½", ⅝", ¾", 1" and 1¼". Stainless Steel.

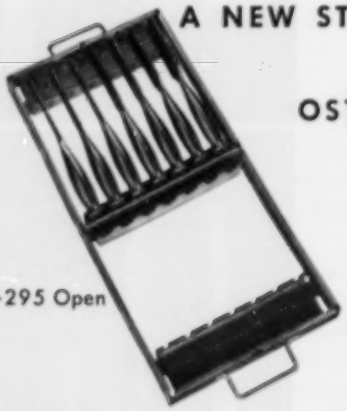
0-255 SMITH-PETERSEN OSTEOTOME—curved, 8", sizes ¼", ⅜", ½", ⅝", ¾", 1" and 1¼". Stainless Steel.

0-260 SMITH-PETERSEN GOUGE—straight, 8", sizes ⅜", 9/16", ¾" and 1". Stainless Steel.

0-265 SMITH-PETERSEN GOUGE—curved, 8", sizes ⅜", 9/16", ¾" and 1". Stainless Steel.

0-270 SMITH-PETERSEN GOUGE—reverse curved, 8", sizes ⅜", 9/16", ¾" and 1". Stainless Steel.

A NEW STAINLESS STEEL CASE TO HOLD SMITH-PETERSEN OSTEOTOMES and GOUGES



0-295 Open

CASE 0-295—holds seven Smith-Petersen Osteotomes.

CASE 0-296—holds seven Smith-Petersen Gouges.

CASE 0-297—holds a combination of seven Osteotomes and Gouges.

Cutting edges are protected at all times. Complete unit may be autoclaved.

0-295 Closed

Specify Width of Gouges and Osteotomes When Ordering

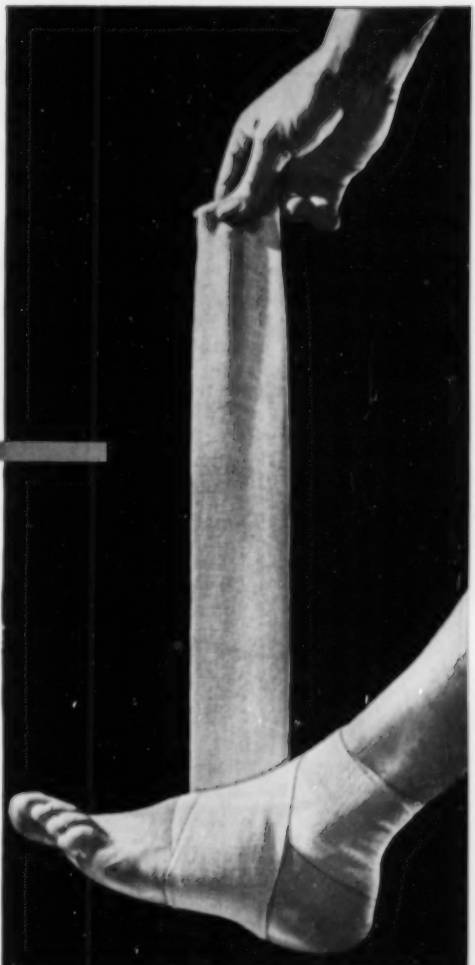
ESTABLISHED 1830

Codman & Shurtleff, Inc.

MAKERS OF SURGEONS' INSTRUMENTS

104 BROOKLINE AVENUE BOSTON 15, MASSACHUSETTS

The first truly elastic bandage that heat won't hurt



New TENSOR is woven with Heat-Resistant live rubber threads for lasting elasticity

It takes live rubber threads to make a truly elastic bandage. Up to now, however, the live rubber has posed a laundry problem, particularly in high temperature home and commercial dryers.

But now, there's a new Tensor that needs no special laundry care—a Tensor that has been tested at 280° F. for hours on end, with no appreciable loss of stretch. So, whether it's new or has been laundered repeatedly, you can always be certain of its uniform, lasting elasticity in use.

And Tensor puts the pressure in *your* hands, Doctor. Whether you bandage for low pressure or high, you get uniform pressure over the entire bandaged area. And Tensor will maintain the pressure *you* apply.

Isn't this the kind of elastic bandage you want *your* patients to wear? Why not have your nurse order them next time she replenishes office medical supplies. Available in doctor bulk put-ups at no increase in cost.

COMPARE THESE ELASTIC BANDAGES

❶ Bandage with ordinary rubber

❷ TENSOR

❶ One-foot length of bandage made with ordinary rubber is stretched after high temperature drying—and stays stretched. Its elasticity "died" in the dryer.

❷ But one-foot length of heat-resistant Tensor snaps back to its original length, even after prolonged exposure to near scorching heat of commercial dryer.

New TENSOR®
ELASTIC BANDAGE
Woven with Heat-Resistant live rubber threads

BAUER & BLACK
Division of The Kendall Company
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If The Shoe Doesn't Fit–

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YOU can depend on Kleistone to meet exactly your requirements for whatever orthopaedic appliances may be necessary. For over thirty years our skilled technicians have been aiding doctors in assuring proper correction or relief for small feet.

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Established 1919
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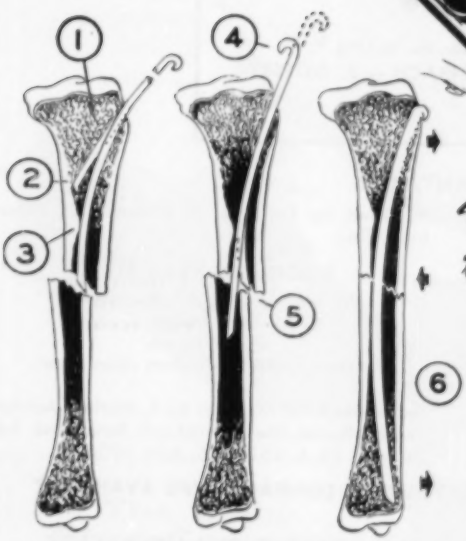
The RUSH MEDULLARY PIN

(PATENTED)

Drives like a Toboggan



Why the Sled-Runner Point

1. TO DRIVE THROUGH CANCELLOUS BONE
2. TO GUIDE PIN DOWN MEDULLARY CAVITY
3. TO SLIDE OVER OBSTRUCTIONS
4. TO ROTATE HEAD ROTATES POINT
5. TO GUIDE BY PIN ROTATION
6. TO CONTROL BONE ROTATION BY POINT PRESSURE

WRITE FOR INFORMATION

NOTE: All authentic Rush Pins bear the trademark BERIVON.®

MFG. EXCLUSIVELY BY:

THE BERIVON Company

P.O. BOX 1851

Meridian, Miss.

NEW STAINLESS STEEL INTRAMEDULLERY
FEMORAL HEAD-NECK PROSTHESIS

Cat. No. M-1776
TYPE LEINBACH — J. GOSSET

ADVANTAGES

Restores normal length of femoral head and neck.

Eliminates torsion and tipping.

Allows distribution of pressure in a vertical plane over a large surface and weight bearing at a more vascularized part of the femur.

Allows reconstruction of normal anteversion.

Less bone absorption.

Modified by Dr. Irwin S. Leinbach, St. Petersburg, Fla.

STANDARD HEAD SIZES
43 mm.–45 mm.–47 mm.–49 mm.
Stem length
8″ or 20 cm.
Eccentric right or left stem upon order.

Technique: Refer to paper by R. Merle d'Aubigne and M. Postel, *The Journal of Bone and Joint Surgery*, 36-A, 451–475, June 1954.

• SPECIAL BROACH AND DRIVER-EXTRACTOR LEINBACH TYPE AVAILABLE

AMERICAN OSSACRYL COMPANY
15 PARK ROW, NEW YORK CITY

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Excellence invites comparison

● Well made shoes do not fear comparison. They welcome it. A comparison of children's shoes readily reveals the excellence in design and construction of Selby Junior Arch Preserver Shoes.

From the construction of the last, skived out on the inner border of the heel to accommodate wedging, and the meticulous selection of highest quality leathers, through each of the one hundred and seventy separate operations that it takes to make a single shoe, no detail is overlooked to make Selby Junior Arch Preservers the best shoes made for infants and children of all ages.

The excellence of Selby Junior Arch Preservers is the result of the knowledge and skill acquired in more than three quarters of a century of fine shoemaking.

When you recommend shoes for children, please remember—Selby Juniors are the only *genuine* Arch Preserver Shoes for children. You can recommend them with complete confidence.

The only genuine Arch Preserver Shoes for children

Selby
JUNIOR ARCH PRESERVER SHOES

● *If Selby Junior Arch Preservers are not available in your city, please write directly to us.*

The Selby Shoe Company
Portsmouth, Ohio

MORE THAN THREE QUARTERS OF A CENTURY OF FINE SHOEMAKING

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LOTTES TRIFLANGE TIBIAL NAIL
Tibial Nail diameters: 5/16" and 3/8"

18-8 SMo Stainless Steel nail made in ½ inch lengths from 9 to 14½ inches.

The triflange nail is also available for femur, humerus, radius, and ulna.

The driver and extractor can be used with any of the triflange nails.

DRIVER AND EXTRACTOR

COMPOUND FRACTURE WHICH WAS DEBRIDED, CLOSED, AND PLACED IN CAST ON ADMISSION

RESULT THREE MONTHS AFTER PRIMARY HEALING OF WOUND AND CLOSED NAILING

For further information, please write to

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3689 Olive Street

for better spinal surgery

tables and tools

by TOWER

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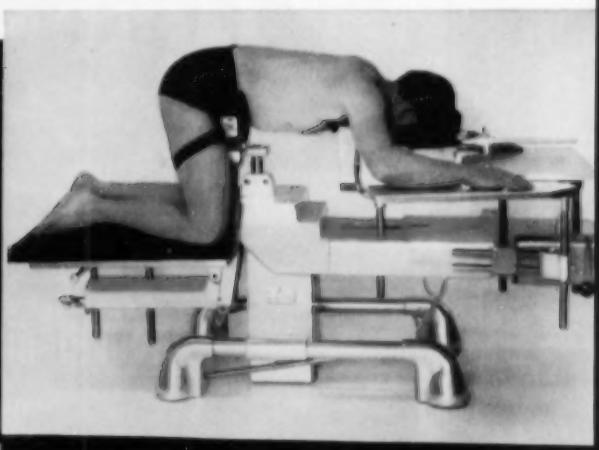
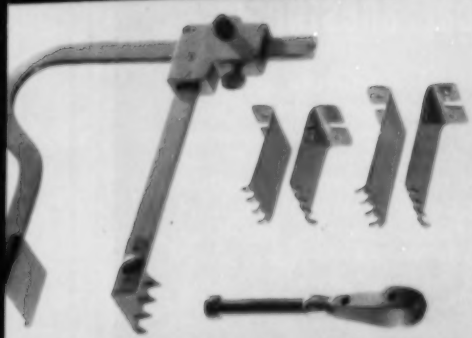
ROGER ANDERSON FRACTURE AND SURGICAL TABLES offer exclusive suspension at the iliac crests and at the upper chest region. Since the patient's thorax and abdomen are unobstructed, he is able to breathe normally and blood loss is held to a minimum.

All weight bearing areas are fully adjustable, so the degree of flexion and extension of the spine is *fully controlled* to give unexcelled laminae separation. Exclusive gear-driven raising of patient's weight at knees. Table may also be quickly leveled. Write for information.





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TOWER SPINE AND LAMINECTOMY RETRACTOR provides superior controlled mechanical retraction. Gear drive gives positive leverage and is easily locked in any position. There are no protruding handles to interfere with surgery. The exclusive *interchangeable* stainless steel jaws will not slip. Complete with wrench and three pairs of jaws ($2\frac{1}{4}$", $2\frac{5}{8}$", and 3"). . . . . $66.00.

Hemi-laminectomy prong . . . . $5.00.

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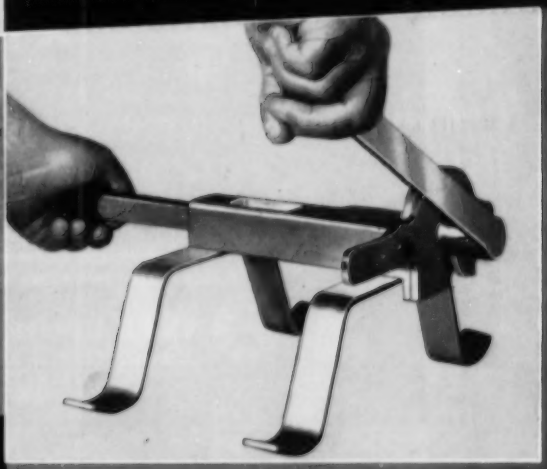
TOWER BONE CRUMBING MILL provides ideal bone crumbs for better surgery. Because of the unique dividing action of this Mill, the entire donor bone is torn into burr-like crumbs. These crumbs are physiologically and structurally superior for use in bone grafts, spinal fusions, spinal arthodeses. Mill easily operated and cleaned . . . no contamination or loss from flying bone chips. Write for information.



Request a free reprint on use of Suboccipital Skeletal Traction on Fracture-Dislocations of the Cervical Spine.

THE TOWER COMPANY, INC.

P. O. BOX 3181, SEATTLE 14, WASHINGTON • FIFTH & STEVENS, GENEVA, ILLINOIS

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Stocked by leading wholesale druggists and surgical supply houses as a ½%, 1% or 2% solution without Epinephrine and with Epinephrine 1:100,000. 2% solution is also supplied with Epinephrine 1:50,000. All solutions dispensed in 50cc. and 20cc. multiple dose vials, packed 5x50cc. or 5x20cc. to a carton.

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Pronounced Xĭ lo'cain

(Brand of lidocaine *HCL)

AN AQUEOUS SOLUTION

A 4th dimensional approach to preferred local anesthesia

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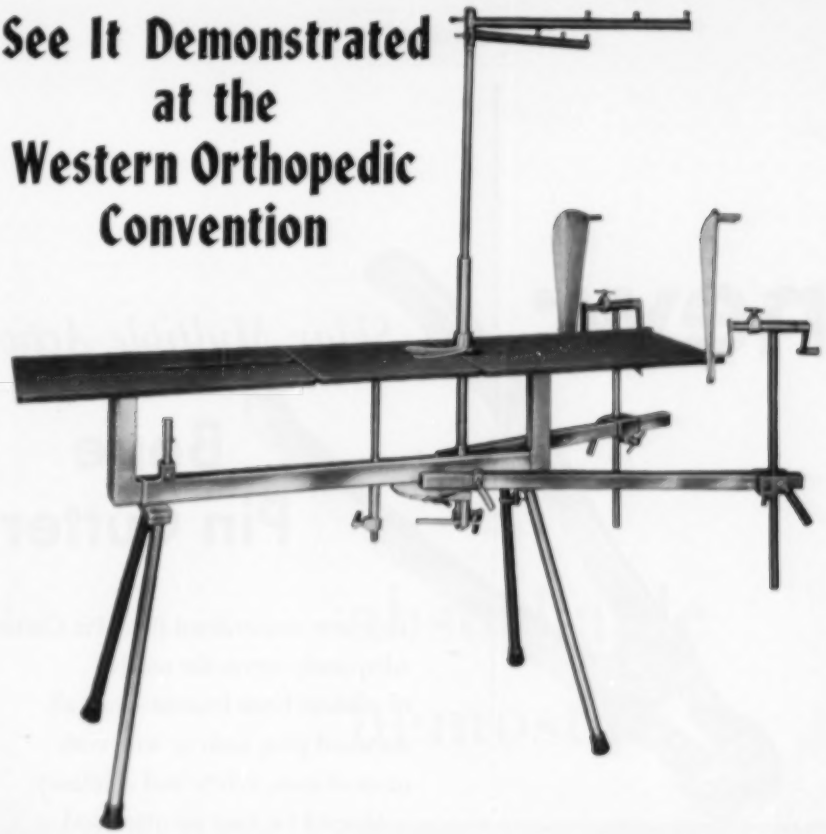
ASTRA PHARMACEUTICAL PRODUCTS, INC.

WORCESTER, MASS. U.S.A.

*U.S. Patent No. 2,441,498

See It Demonstrated at the Western Orthopedic Convention



Virgin Fracture Table

MODERN • SIMPLE • PORTABLE • ECONOMICAL

The VIRGIN Fracture Table is the very newest in Fracture Tables. It is simple in design but of the sturdiest construction. The "saw horse" construction prevents tipping. The heaviest patient can be handled with ease. It can be moved about easily, one person handling it nicely. The total weight of the table is approximately 130 lbs. Demounted it occupies a space 36 by 24 inches. **Its portability and demountability for storage are outstanding features.** It can be carried in an automobile or stored in a cabinet. It is ideal equipment for offices, clinics, emergency rooms, extra cast rooms, small hospitals and for children's hospitals.

Write for illustrated folder which shows table used for four major procedures — Hip Spicas, Shoulder Spicas, Hyper-extension and Cervical Spine Casts. At extra cost the Table can be equipped for Hip Nailing.

GILBERT HYDE CHICK COMPANY

***Main Office and Factory:* 821 Seventy-Fifth Avenue, Oakland 21, California**

new: *Sklar Multiple Action* Bone Pin Cutter

CAT. No. 250-145

This new, streamlined Bone Pin Cutter adequately serves the needs of modern bone fixation—cuts all standard pins, nails or wire with unusual ease, safety and efficiency.

Shaped for easy insertion and manipulation in open wounds—chrome-plated to resist corrosion—this Sklar instrument is 15″ in length, and of long-handled construction for extra-strong leverage.

Priced at $18 each. Available through surgical supply houses.

Sklar Specialties in Stainless Steel Developed for the Orthopedic Surgeon

Colclough Laminectomy Rongeur
Hibbs Chisels, Gouges and Osteotomes
Meyerding Aluminum Mallet, Improved Model
Meyerding Bone Skids
Meyerding Chisels, Facet Eroders, Gouges and Osteotomes
Meyerding Finger Retractors
Meyerding Hip and Shoulder Bone Skid
Meyerding Laminectomy Retractor
Meyerding Self Retaining Retractors, True-Grip Ratchets
Michele Trephines
Putti Arthroplastic Gouges
Sheldon Hemilaminectomy Retractor

Literature upon request.

CAUTION – if the name Sklar is not stamped on the instrument it is not a genuine Sklar product.

J. SKLAR MANUFACTURING COMPANY
38-04 Woodside Avenue, Long Island City 4, N. Y.

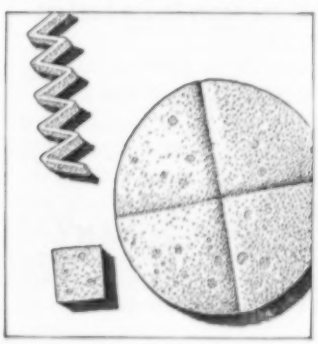
Upjohn

absorbable hemostat:

Available in a large variety of sizes and forms, including:

Surgical sponges
Compressed surgical sponges
Dental packs
Gynecologic packs
Nasal packs
Prostatectomy cones
Tumor diagnosis kit

The Upjohn Company, Kalamazoo, Michigan



Gelfoam

Trademark Reg. U.S. Pat. Off. BRAND OF ABSORBABLE GELATIN SPONGE

NEW MELMAC® BANDAGE provides greatly increased strength, especially in the critical early stages when ordinary plaster casts break down so easily. Bandage for bandage, MELMAC has as much *as 2 to 4 times the strength of plain plaster.*

NEW—A MAJOR ADVANCE

IN PLASTER CAST TECHNIQUE

Now MELMAC® resin plaster of Paris and catalyst combined in one ready-to-use bandage.

With this revolutionary new material, MELMAC *resin* plaster of Paris BANDAGE, you can form stronger, lighter, thinner, water-and-urine-resistant casts and splints of every type and size required. There is nothing new to learn. Simply work with fewer bandages because MELMAC BANDAGE makes casts with greatly increased strength. Use it instead of plaster in fractures and preoperative, postoperative and corrective surgical procedures. 1. Just dip MELMAC BANDAGE into tepid water for 5 to 10 seconds. Squeeze out excess water *thoroughly*. Apply. 2. Use about half the usual number (or less). 3. Result: strong, light, thin water-resistant casts—no frayed edges. 4. Same disposal of waste as with ordinary plaster of Paris. 5. Remove thin cast easily with cast cutter, knife or cast saw.

PATENT APPLIED FOR

In answering advertisements, please mention *The Journal of Bone and Joint Surgery.*

1. *More durable—to withstand hard usage on the job.* Casts of MELMAC BANDAGE take punishment of blows and sharp objects. Less need for recasting.

2. *Lighter weight—less bulk—on this 210 lb. patient.* New casts, about half the weight of plaster, encourage *mobilization of joints* to prevent stiffness. Patient easier to lift and move in hospital and at home. Lighter casts speed recovery, shorten hospitalization.

HANDY-TO-USE ROLLS AND SPLINTS OF MELMAC RESIN PLASTER OF PARIS BANDAGE

Bandages (rolls)	Size	2" x 3 yds.	3" x 3 yds.	4" x 3 yds.
	Product No.	2122	2123	2164
	Size	4" x 5 yds.	6" x 3 yds.	6" x 5 yds.
	Product No.	2124	2166	2126

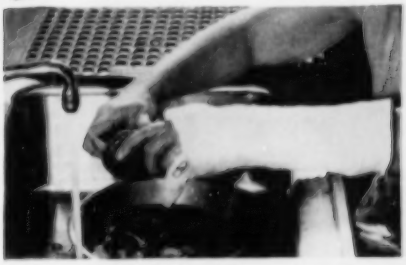
Splints	Size	3" x 15"	4" x 15"
	Product No.	2133	2134

Sensitivity. Since this product may contain traces of formaldehyde, persons who are known to be sensitive to it should be observed closely for dermatitis. Operators using the bandage repeatedly should wear rubber gloves if skin sensitivity exists.

BRING YOUR OLD TYPE PLASTER OF PARIS BANDAGES UP TO DATE.

Dissolve MELMAC® Orthopedic Composition, a powder, in water in which ordinary plaster bandages are wet and you will have a cast that is comparable to the new MELMAC BANDAGE cast.

3. *Less recasting—new casts resist water and urine.* Cast of MELMAC BANDAGE resists wetting and protects against other housework hazards which would decompose plaster. Washable with soap and water. *Porous,* to permit free passage of air or exudates.



4. *Thinner casts—clearer x-rays.* X-rays penetrate thin "shell" of MELMAC BANDAGE cast for clear x-ray of congenital hip, so difficult with thick plaster.

Davis & Geck

MELMAC®

resin plaster of Paris **BANDAGE**

DAVIS & GECK, Inc., a unit of American Cyanamid Company, Danbury, Connecticut.

Sutures and Surgical Specialties

*A dynamic approach to better health for the aging patient**

IN THE 40's AND 50's

"disease or body change is lurking in the background"† even though the individual may feel in good health. In this age group "Mediatric"* will help prevent premature atrophic changes due to waning sex hormone function and inadequate nutrition.

IN THE 60's AND 70's

involutional changes become increasingly apparent as the body loses its ability to resist environmental stress. "Mediatric"* will aid the aging economy cope more successfully with three important stressors: gonadal hormone imbalance, dietary insufficiency, and emotional instability.

IN THE 70's AND 80's

functional impairment is at its peak and, in most cases, is the end result of progressive disorders which had their onset in the forties. Patients treated with "Mediatric"* have responded with increased physical vigor, improved muscle tone, and better emotional balance.

†Kountz, W. B.: J.A.M.A. *153*:777 (Oct. 31) 1953.

* "MEDIATRIC"®

Steroid-nutritional compound

STEROIDS . . . to counteract declining sex hormone function
NUTRITIONAL SUPPLEMENTS . . . to meet the needs of the aging patient
A MILD ANTIDEPRESSANT . . . to promote a brighter mental outlook

Ayerst

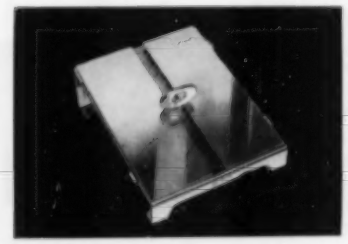
Ayerst Laboratories
New York, N. Y., Montreal, Canada

Capsules, No. 252 — bottles of 30, 100, and 1,000.
Liquid, No. 910 — bottles of 16 fluidounces and 1 gallon.

5416

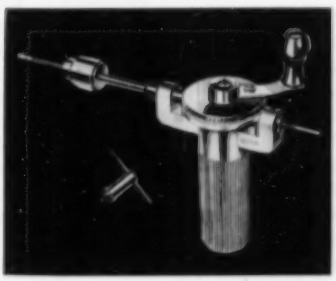
Average dosage, 1 capsule or 3 teaspoonfuls of liquid, daily.

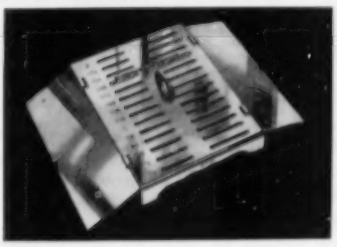
4 NEW TOOLS for the ORTHOPEDIC SURGEON



De Puy Drill for Small Bones

Especially for hand surgery and other small bones. Weighs under one pound. Canulated full length for 3/32" wires.



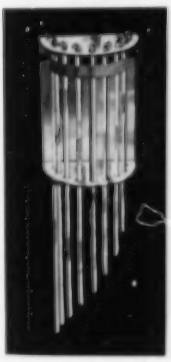


Economy Bone Screw Rack

A screw rack designed to be easily portable, moderate in price. Slots with the size clearly marked holds 14 dozen screws from 5/8" to 2" long. The hinged top closes the unit so that screws cannot fall out. The lock which holds the covers also serves as a handle. Stainless steel, entire unit can be sterilized.

De Puy DIAMOND Intramedullary Pins

Diamond shaped to prohibit rotation of fragments. 1" to 14" long, 4 x 6 mm., 5 x 5 mm. and 2 x 3 mm. diameter. In three sets for humerus and tibia, radius and ulna, small bones.



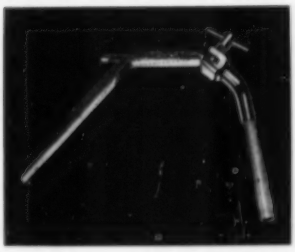


PLATE Bending Wrench

A special wrench for bending even heavy gauge intertrochanteric plates. Bend to any angle *without distorting* fixation hole. Makes it easy to precisely change angle of all plates.

WRITE FOR COMPLETE DESCRIPTION and PRICES

De Puy **MANUFACTURING CO., INC.**
WARSAW, INDIANA

• The Clinical Approach to Prosthesis •

The Clinical Approach at the Woodrow Wilson Rehabilitation Center, Fisherville, Virginia, features the Clinical Team—the *Orthopedist*, the *Prosthetic Technician* (a HANGER Certified Prosthetist), the *Physical Therapist*, and the *Occupational Therapist* (for arm amputees only).

All amputee patients are examined by this Clinical Team with the complete medical history and other records at hand. During the examination the patient is analyzed as an individual case with his particular advantages and limitations evaluated in relation to the possible courses of treatment. For example, whether a particular stump

or joint condition can be corrected with therapy, or with special prosthesis fitting and construction; if not, is further surgery desirable. Then a course of rehabilitation is prescribed by the Orthopedist, including the Physical (and Occupational for arm amputees) Therapy necessary, the type of Prosthesis to be worn, and other special treatment or training required.

Immediately the patient's treatment by the Center begins according to the Prescription. The patient receives pre-prosthetic therapy in which the stump is conditioned to provide the most efficient use of the Prosthesis. He is supervised and treated in baths, heat, exercise, etc., by therapists and nurses specially-trained for this work.

When the patient actually begins to wear the prosthesis, the Clinical Team again works closely together in the rehabilitation program. The Prosthesis itself has been fabricated according to the measurements and specifications taken by the Prosthetist member of the Clinical Team. Careful attention is now given to fitting adjustments, continued therapy, and training exercises, such as walking, sitting, steps, etc. Unusual problems are cause for a complete review and possible change of prescription. For arm amputees, Occupational Therapy now becomes important, and the amputee spends part of each day learning to use the Prosthesis and to live an independent life. Trained Therapists and nurses supervise the teaching of dexterity and manipula-

tion through blocks, games, doorknobs, faucets, tools, etc.

Most patients are ready for discharge in about six weeks. Each must appear at the Clinic for a final Prosthetic Performance Check-out by the Clinical Team and Official release by the Orthopedist.

This is one of many such Centers throughout the country where HANGER Technicians function as integral members of the Clinical Team. Each is an ABC Certified Prosthetist, and trained in Team rehabilitation. Feel free to call on any HANGER office for service at any time.

• • • • • • • Hanger PROSTHESIS • • • • • • •

ATLANTA 1, GA.
BALTIMORE 1, MD.
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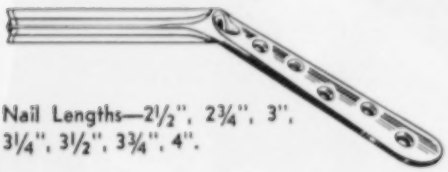
Jewett ONE-PIECE NAIL . . . AND COMPLETE SET OF INSTRUMENTS.

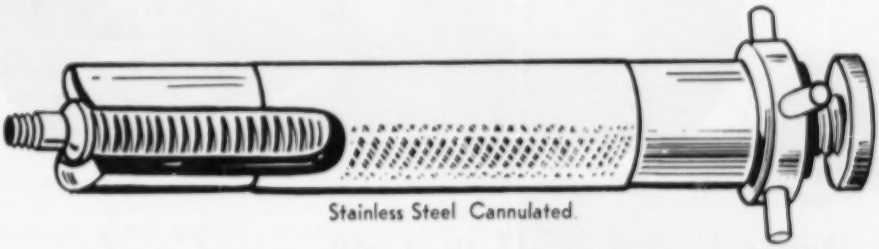
No. 224J—Jewett One-Piece Hip Nail. Drop forged SMO Stainless Steel—Cannulated.



Nail Lengths—2½", 2¾", 3", 3¼", 3½", 3¾", 4".

Plate Lengths—4", 5", 6".

No. 226 Guide for Jewett Hip Nail Stainless Steel

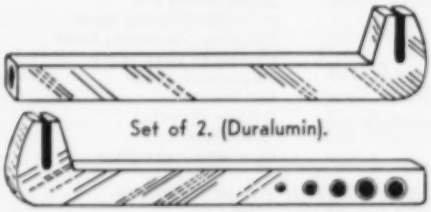


Stainless Steel Cannulated

No. 208J Extractor-Impactor for Jewett One Piece and Smith Petersen Hip Nails.

No. W402J Henderson Cortex Reamer. Cannulated. Fits Jacobs Chuck. Stainless Steel.

No. 225 One-Piece Nail Driver. For Jewett Nails. Stainless Steel. Cannulated.



Set of 2. (Duralumin).

No. 219J Jewett Nail Plate Bending Irons.

Illustration shows one of many uses of plate bending irons.

WRIGHT MANUFACTURING COMPANY

739 JACKSON AVENUE • TELEPHONE 37-2769 • MEMPHIS 5, TENNESSEE

New... BISHOP EXPLOSION-PROOF *Electric* BONE SAW

by Orthopedic

Here's **ASSURED SAFETY** in a saw that both oscillates and rotates!

Now, you can meet the long-felt demand for a fully explosion-proof surgical saw with foot control that retains all the advantages of oscillation and rotation.

- Fully conforms to safety requirements for Class 1, Group C, Hazardous Locations.
- Approved by Underwriters' Laboratories, Inc. for use in locations containing highly combustible anesthetic agents.
- All blades, attachments and accessories used with the original Bishop Orthopedic Electric Bone Saw are interchangeable with this new explosion-proof unit.

Complete

OUTFIT INCLUDES

- Explosion-proof Motor Unit
- Explosion-proof Variable-Speed Foot Switch
- Special Extension Cord with Fittings
- Arbor complete with 2 Circular Saws
- 2 Curetting Burrs
- 6 Slotting Burrs
- 4 Twist Drills
- Jacobs Chuck Key
- 2" Oscillating Saw Blade
- Cut-away Oscillating Blade
- Oscillating Bone Scoop
- Single Blade Arbor
- End Wrench
- 2 Bristo Wrenches
- Fitted Case
- Operating Instructions

Available through surgical supply dealers

Orthopedic EQUIPMENT CO.
BOURBON, INDIANA

SPLINTS • FRACTURE EQUIPMENT • SMo INTERNAL BONE APPLIANCES • BONE INSTRUMENTS

goldthwait type

chair back type

taylor type

no waiting for treatment

with CAMP plastic braces

Authorized Camp Dealers carry Camp Plastic Braces in stock — providing immediate delivery for treatment of patients.

And Camp Plastic Braces can be molded by hand, after heating under an infra-red lamp. When cool, they remain as rigid as steel.

They are available in Goldthwait, Taylor, Chair Back, or Cervical Types, in various heights and sizes.

1. Functionally correct anatomical design.
2. Washable, for elimination of perspiration odors.
3. Comfortable, cooler — reduces possibility of skin irritation.
4. Inconspicuous, lightweight.
5. Rigid support.
6. Plastic construction permits X-rays without removing braces.

cervical type

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S. H. CAMP & COMPANY, JACKSON, MICHIGAN

World's Largest Manufacturers of Anatomical Supports

OFFICES: 200 Madison Ave., New York; Merchandise Mart, Chicago

FACTORIES: Windsor, Ontario; London, England

In answering advertisements, please mention *The Journal of Bone and Joint Surgery.*

Sabel's *Open Toe Pre-Walker Club Foot Shoe

** This latest Pre-Walker Club Foot shoe will allow for closer fittings. It will enable you to see that the toes are in correct position, and that the heel is well down in the shoe.*

for INFANTS

SABEL'S CLUB FOOT SHOE

TRADE MARK REG. U.S. PAT. OFF.

CARRIED IN STOCK

The Pre-Walker Surgical shoe with OPEN TOE, the matching shoe where only one foot requires the Pre-Walker Club Foot Shoe.

Strap over instep holds heel down into place

RIGHT

Sole removed to show flat steel plate extending from heel to toe

LEFT

THIS Pre-Walker Club Foot shoe is designed and made for infants to be worn until the child can stand or walk alone. The "PRE-WALKER" Club Foot shoe can be worn by the infant at all times, and also can be kept on while the child is in bed. Its function is to keep the foot in the exact position that the physician has obtained.

As the infant progresses to the point of walking or standing alone and further corrections are required, then the regulation Sabel Club Foot shoe can be used until the fixation desired has taken place.

I. SABEL, Inc.

1207 Chestnut Street Philadelphia 7, Pa.

BOOKLET WITH COMPLETE DETAILS ALSO DEALERS' NAMES UPON REQUEST

Made Exclusively by

THOMPSON BROS. SHOE CO., Brockton, Massachusetts

And Now

SOMETHING NEW CAN BE ADDED TO

THE BETTER HYPEREXTENSION brace by blair's

MODEL E-36 WITH
C-41 CERVICAL ATTACHMENT

MODEL E-36

- Less Bulky • Easier Applied
- Most Comfortable • More Freedom of Action
- More Posture Conforming • Less Pressure Discomfort
- Better Patient Acceptance • Easy to Attain Hyperextension
- Lever Action Hyperextension Pull
- Simple Telescoping Size Adjustment •

LESS EXPENSIVE

PATENTED

ORDER WITH CONFIDENCE • IF NOT ENTIRELY SATISFIED
RETURN WITHIN 10 DAYS. • NO OBLIGATION

Blairs Associate
MANUFACTURERS OF SURGICAL & ORTHOPEDIC APPLIANCES

P. O. BOX 362, 913 KUHL AVENUE, ORLANDO, FLORIDA

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The Editorial Office of *The Journal* is constantly having calls for back issues of *The Journal* and desires to know where copies of the following issues may be obtained when needed:

THE AMERICAN JOURNAL OF ORTHOPEDIC SURGERY

1903–1904: Vol. I, Nos. 1, 2, 3, and 4; August, November 1903; February, May 1904.
1904–1905: Vol. II, Nos. 1, 2, 3, and 4; August, October 1904; January, April 1905.
1905–1906: Vol. III, Nos. 1, 2, 3, and 4; July, October 1905; January, April 1906.
1906–1907: Vol. IV, Nos. 1, 2, 3, and 4; July, October 1906; January, April 1907.
1907–1908: Vol. V, Nos. 1, 2, 3, and 4; July, October 1907; January, April 1908.
1908–1909: Vol. VI, Nos. 1, 2, 3, and 4; August, November 1908; February, May 1909.
1909–1910: Vol. VII, Nos. 1, 2, 3, and 4; August, November 1909; February, May 1910.
1910–1911: Vol. VIII, Nos. 1, 2, 3, and 4; August, November 1910; February, May 1911.
1911–1912: Vol. IX, Nos. 1, 2, 3, and 4; August, November 1911; February, May 1912.
1912–1913: Vol. X, Nos. 1, 2, 3, and 4; August, November 1912; February, May 1913.
1913–1914: Vol. XI, Nos. 1, 2, 3, and 4; July, October 1913; January, April 1914.
1914–1915: Vol. XII, Nos. 1, 2, 3, and 4; July, October 1914; January, April 1915.
1915: Vol. XIII, Nos. 1 and 2; July, October.
1916: Vol. XIV, all twelve issues.
1917: Vol. XV, all twelve issues.
1918: Vol. XVI, all twelve issues.

THE JOURNAL OF ORTHOPAEDIC SURGERY

1919: Vol. I, all twelve issues.
1920: Vol. II (Old Series Vol. XVIII), all twelve issues.
1921: Vol. III (Old Series Vol. XIX), Nos. 1, 2, 3, 4, 6, 9, 10, 11, and 12; January, February, March, April, June, September, October, November, and December.

THE JOURNAL OF BONE AND JOINT SURGERY

1922: Vol. IV (Old Series Vol. XX), Nos. 1, 2, and 3; January, April, and July.
1923: Vol. V (Old Series Vol. XXI), Nos. 1, 2, 3, and 4; January, April, July, and October.
1924: Vol. VI (Old Series Vol. XXII), Nos. 1, 2, 3, and 4; January, April, July, and October.
1925: Vol. VII (Old Series Vol. XXIII), No. 1; January.
1926: Vol. VIII (Old Series Vol. XXIV), Nos. 1, 2, 3, and 4; January, April, July, and October.
1927: Vol. IX (Old Series Vol. XXV), Nos. 1, 2, 3, and 4; January, April, July, and October.
1928: Vol. X (Old Series Vol. XXVI), Nos. 1, 2, and 3; January, April, and July.
1929: Vol. XI (Old Series Vol. XXVII), Nos. 1, 2, and 4; January, April, and October.
1930: Vol. XII (Old Series Vol. XXVIII), Nos. 1 and 2; January and April.
1931: Vol. XIII (Old Series Vol. XXIX), No. 1; January.
1932: Vol. XIV (Old Series Vol. XXX), No. 4; October.
1933: Vol. XV (Old Series Vol. XXXI), No. 1; January.
1934: Vol. XVI (Old Series Vol. XXXII), No. 4; October.
1935: Vol. XVII (Old Series Vol. XXXIII), Nos. 1, 2, 3, and 4; January, April, July, and October.
1937: Vol. XIX (Old Series Vol. XXXV), Nos. 1, 3, and 4; January, July, and October.
1938: Vol. XX (Old Series Vol. XXXVI), Nos. 1, 2, 3, and 4; January, April, July, and October.
1939: Vol. XXI (Old Series Vol. XXXVII), Nos. 1, 2, 3, and 4; January, April, July, and October.
1940: Vol. XXII (Old Series Vol. XXXVIII), No. 1; January.
1941: Vol. XXIII (Old Series Vol. XXXIX), No. 1; January.
1944: Vol. XXVI (Old Series Vol. XLII), Nos. 1, 2, 3, and 4; January, April, July, and October.
1945: Vol. XXVII (Old Series Vol. XLIII), No. 2; April.
1947: Vol. XXIX (Old Series Vol. XLV), Nos. 1, 2, and 3; January, April, and July.
1948: Vol. XXX-A, No. 1; January.

Any reader having copies of the above, which he is willing to dispose of, is requested to correspond with the Editor.

In answering advertisements, please mention *The Journal of Bone and Joint Surgery.*

VOL. 36-A, NO. 5 OCTOBER 1954

The Journal of
Bone and Joint Surgery

American Volume

IMMUNIZATION IN POLIOMYELITIS *

BY HART E. VAN RIPER, M.D., NEW YORK, N. Y.

Medical Director, The National Foundation for Infantile Paralysis

The National Foundation for Infantile Paralysis is now sponsoring a nationwide field trial of an inactivated polyvalent poliomyelitis vaccine developed by Dr. Jonas Salk [20, 21, 23] of the University of Pittsburgh. This trial was made possible by the generous cooperation of the medical profession, state and local health officers, nursing organizations, school authorities, school teachers, lay volunteers, parents, and children. The first inoculations outside Allegheny County, Pennsylvania, where Dr. Salk conducted his preliminary investigations, were given on April 26, 1954.

The second phase of the field trial, the period of observation and follow-up of all cases of poliomyelitis occurring among children in the test groups, will continue throughout the poliomyelitis season, roughly through October. Then we come to the final phase, the clinical, epidemiological, and statistical evaluation of all the data on the effectiveness of the Salk vaccine. However, a definitive evaluation report cannot be expected until 1955, probably in the spring of the year.

The official evaluation reports will be issued from the Poliomyelitis Vaccine Evaluation Center, which has been established at the University of Michigan under the direction of Dr. Thomas Francis, Professor of Epidemiology. This center was established, with support from The National Foundation, exactly for the purpose of obtaining an objective, unbiased, perfectly independent evaluation of the Salk vaccine and the field trial in all its phases. A large staff is required, and elaborate procedures have been worked out for processing an immense amount of data. For example, an individual record punch-card will be prepared for every child whose name appears on the registration schedules in all the 217 test areas throughout this country and in a few test areas in Canada and Finland.

Presented here is principally a discussion of the factors which will bear upon the final evaluation of the Salk vaccine. This will, of necessity, include some consideration of the plan of research which leads up to the evaluation.

PLAN AND SCOPE OF FIELD TRIALS

The basic plan and scope of the field trials is this:

It is being conducted, as originally planned, in 217 selected test areas in forty-four states in the United States. However, additional areas in Canada and Finland were added to the study.

Between April 26, 1954, and July 10, 1954, approximately 625,000 children received three injections each. About 425,000 of them received the vaccine developed by Dr. Salk. About 200,000 received a control substance, a placebo known to have no antigenic effect. The actual placebo was a solution of Mixture 199, the synthetic nutrient in which monkey-kidney cells used in the manufacture of vaccine are grown. About 1,200,000 other children

* Read at the Annual Meeting of The American Orthopaedic Association at Bretton Woods, New Hampshire, June 9, 1954.

in the same age group (six to eight years) as those injected have also participated in the field trials as "observed controls". Their health records are being used for study and comparison.

It should be understood that two types of observed groups are being used in this nationwide and international study. We speak of the placebo control areas, ninety-one in number, in which half the children in the first three grades in school receive vaccine and half receive placebo. We also speak of observed control areas, 126 in number, in which all children in the second grade in school receive vaccine injections, while children in the first and third grades, who receive no injections, are nevertheless registered in the study and serve as an observed control group.

Each vaccinated child received three inoculations of one cubic centimeter each of the Salk vaccine in the left triceps muscle. The second inoculation was given one week after the first, the third inoculation four to five weeks later. Placebo injections followed the same schedule. The code distinguishing between vaccine and placebo inoculations is known only to the evaluation center at the University of Michigan.

The time interval between inoculations is an important consideration. The vaccine apparently follows the immunologic pattern of initial sensitization, followed by a booster response. Salk's studies have shown that the antibody level following the booster shot is very greatly increased.

SAFETY OF THE SALK VACCINE

In the preliminary stages of the present field trial, questions were raised, properly and improperly, concerning the safety of the Salk vaccine. Today, we can say categorically that the vaccine is safe. Every batch of vaccine manufactured according to the protocols established by Dr. Salk [22, 24] and the Vaccine Advisory Committee of The National Foundation is laboratory-tested for safety by the manufacturer, by the Laboratory of Biologics Control of the National Institutes of Health, and by the Virus Research Laboratories of the University of Pittsburgh (Dr. Salk's laboratory). Equally important, vast field experience with the commercially manufactured vaccine has already demonstrated its safety. Untoward reactions have been minimal. This is a safe vaccine.

THEORY OF PREVENTION

The basic question that the present vaccine field trials may be expected to answer is, "*To what extent* does vaccination protect against paralytic poliomyelitis under natural conditions of exposure?" Put another way, "Exactly what kind of protection does the Salk vaccine offer?"

Dr. Salk's own careful but numerically limited studies in the Pittsburgh area have indisputably demonstrated that his vaccine, manufactured and administered under approximately the same conditions prevailing in the field trials, does induce a high level of antibody formation in most vaccinated subjects. The question remains, however, as to whether the production of a certain level of antibodies in a high proportion of vaccinated individuals actually has a corresponding effect upon the prevention of paralytic poliomyelitis.

Only the large-scale field trials still under way can answer this question. The incidence of paralytic poliomyelitis is too low to permit us to obtain statistically valid information unless a large number of individuals, on the order of at least half a million, are included in the trial. It should be noted, however, that this field trial will answer questions about immunization in poliomyelitis more quickly and more certainly than can usually be expected in the evaluation of any kind of a prophylactic or therapeutic medical procedure.

Obviously, we hope and expect that the Salk vaccine will work, that, practically speaking, it will provide a high degree of protection against paralytic poliomyelitis. Unless we thought so, we would hardly be justified in spending $7,500,000 of the public's money to prove it.

Yet it must be admitted that this is a great hypothesis in prevention. The theoretical and laboratory-supported evidence for its success far outweighs the available clinical and statistical evidence, which, we hope, will be augmented by the field trial.

Clinical evidence for the effectiveness of the Salk vaccine was simply this. Before the poliomyelitis season of 1953, Dr. Salk had administered his vaccine to approximately 600 individuals. Of this group, 474 were children between the ages of four and twelve. None contracted poliomyelitis in 1953; seven were known to have been exposed to the disease in intimate contacts. Of these seven, we can presume that three were probably infected, since a rise in the antibody titer of their blood was discovered at the end of the poliomyelitis season. In these cases, the infection itself probably served as a booster shot.

This limited clinical experience, statistically unconvincing, nevertheless showed a definite trend when considered in the light of all the theoretically sound data that a safe and practical vaccine was at hand.

BRIEF HISTORY OF IMMUNIZATION AGAINST POLIOMYELITIS

The possibility of producing active or passive immunization against poliomyelitis in human beings has been considered seriously ever since the experimental transmission of the disease to animals was accomplished in 1908. Simon Flexner and P. A. Lewis presented a paper on active immunization and passive serum protection against experimental poliomyelitis in monkeys in 1910. European investigators, such as Karl Landsteiner, C. Levaditi, A. Netter, and P. H. Römer, also followed this clue in the same year.

For more than three decades, however, investigations on immunization against poliomyelitis were hampered by sources of error, either unrecognized or uncorrectable with the methods available at the time. Boyd, who has recently reviewed the voluminous literature on the subject, points out that the most serious sources of error were (1) lack of quantitative methods of assaying virus and antiserum, (2) ignorance of immunologic differences among poliomyelitis viruses, and (3) use of inappropriate animal species and routes of inoculation for testing resistance to infection conferred by immunizing procedures. Nevertheless two fairly large-scale but unsuccessful attempts [1, 4, 14, 15] to introduce a vaccine against poliomyelitis were made in the 1930's by Kolmer and Brodie.

Since that time, new lines of research have brought both active and passive immunization of human beings against poliomyelitis into the realm of practicality. Among the key steps in recent research have been the development of tissue-culture techniques, virus typing, the demonstration of viraemia, and successful field trials with gamma globu lin.

In 1949, Enders and his associates [6] at Harvard showed that the poliomyelitis virus could be grown *in vitro* on other than nerve tissue,—for example, embryonic skin and monkey kidney[25]. This discovery broke a great bottleneck in research in poliomyelitis by freeing it from exclusive dependence on monkeys. Tissue-culture techniques now provide methods of growing virus in quantity and of testing easily for the presence of virus and the level of antibody.

In 1951, a co-ordinated research program in four universities completed testing several hundred strains of poliomyelitis virus and arrived at the conclusion that there were three immunologically distinct types, each capable of causing paralytic poliomyelitis.[5] These types are designated as Types 1, 2, and 3 (respectively, Brunhilde, Lansing, and Leon types). Obviously, any effective vaccine must protect against all three types.

In 1952, Bodian of Johns Hopkins and Horstmann of Yale revealed the unexpected experimental fact that poliomyelitis virus could be demonstrated in the blood stream early in the prodromal stage of the disease. This demonstration of a stage of viraemia, before the virus entered the central nervous system, greatly enhanced the probability that any method of getting circulating antibodies into the blood stream at the proper time would protect against paralysis by blocking the virus before it reached the central nervous system.

In 1951 and 1952, Hammon [8, 9, 10, 11] and his associates conducted a large-scale controlled experiment on passive immunization against poliomyelitis in man with the use of gamma globulin prepared from immune blood. These studies, which have never been refuted, showed that gamma globulin given in adequate amounts and at the right time definitely provides a temporary (six to eight weeks) protection against paralytic poliomyelitis. Under proper conditions of administration, it is about 88 per cent. effective.

This research, and much more not cited, set the stage for the development and trial of the Salk vaccine, which includes virus Types 1, 2 and 3 completely inactivated by formalin. If passive immunization can protect against poliomyelitis, as has been shown, active immunization, which provides a much higher level of circulating antibodies, should be even more effective.

A Few Words about Gamma Globulin, 1954

Gamma globulin, for passive immunization, became available during the summer of 1954 in about twice the quantity available in the summer of 1953 and could be used earlier. Its distribution is in the hands of the Office of Defense Mobilization. Locally it is available through state health officers and county health officers.

While we are testing for the effectiveness of the Salk vaccine, it nevertheless deserves to be pointed out that gamma globulin is still the only presently proved and available prophylactic weapon against poliomyelitis.

The most recent report from Hammon and his associates [12], presented before the American Medical Association in June 1954, indicated that the protection afforded by gamma globulin began earlier and lasted longer than they had previously stated. They also presented evidence that gamma globulin has been useful in preventing paralytic poliomyelitis when administered to intimate and household contacts of index cases of poliomyelitis.

Hammon's new studies include a re-analysis of cases in which the diagnosis of poliomyelitis was confirmed by laboratory (mainly tissue-culture) studies. The new data also suggest that gamma globulin given during the incubation period has a beneficial effect in the direction of modifying the amount of muscle involvement from the infection and reducing the extent of residual paralysis.

If the Salk vaccine were not in the offing, I think there might be less hesitancy on the part of the profession to make use of gamma globulin.

EVALUATION STUDIES

Muscle Evaluation

The total plan of study set up for the 1954 poliomyelitis vaccine field trials will enable us, once the evaluation has been completed, to speak with a very high degree of assurance concerning the amount and kind of protection against paralytic poliomyelitis afforded by the Salk vaccine. In the first place, it is unlikely that many, if any, cases of paralytic poliomyelitis will fail to be diagnosed among children in the study. Careful consultation and follow-up studies of every suspected case are planned. Secondly, the presence of registered-in-advance control groups, particularly the control groups of children who received placebo injections, will give high validity and reliability to the findings. Thirdly, the amount of paralysis in any given case will be carefully recorded.

Special attention should be called to the plan for muscle evaluation of all patients in the vaccinated and control groups who came down with paralytic poliomyelitis in any degree during the summer of 1954. Every patient is being given two standardized examinations for muscle involvement. The first is given ten to twenty days after the onset of the disease; the second, fifty to seventy days after onset. In this way, not only the initial amount of muscle involvement can be evaluated, but also the degree of recovery from paralytic poliomyelitis can be fairly accurately calculated. The interesting thing about this phase of the study is that it will not only yield data on individual patients, which are

common, but will also give an over-all, nationwide picture, statistically reliable, on the norms of muscle involvement and recovery in both vaccinated and unvaccinated children.

A standardized special muscle-evaluation form has been devised to meet the specific requirements of our study. Muscles listed for strength grading are limited to major muscles. For simplicity in grading and recording, muscles are grouped where possible,—for example, the finger flexors are graded as a group. The grading system records muscle strength as normal, good, fair, poor, trace, or no power.

Because we are dealing with poliomyelitis, the evaluation of respiration, voice quality, deglutition, and mastication, as well as palatal, tongue, and facial muscle involvement, will also be recorded (not graded) as normal or not normal. A scoring system, relating muscle bulk and strength grading based on direct examination, has also been worked out. For individuals and for groups as a whole, we shall, therefore, be able to speak accurately of a *percentage* of loss of normal effective muscle bulk as a result of paralytic poliomyelitis.

The abridged and standardized method just described for muscle testing of poliomyelitic patients was devised by Dr. Jessie Wright, Medical Director, and associates at the D. T. Watson School of Physiatrics, Leetsdale, Pennsylvania, affiliated with the University of Pittsburgh School of Medicine. A special orientation course in the application of the method was given to thirty-five well trained physical therapists, recruited by the American Physical Therapy Association, who are traveling throughout the country to make muscle evaluations on children contracting poliomyelitis in any of the vaccine field-trial test areas.

The physical therapist's findings will in every case be reviewed and evaluated by the physician attending the patient; and he, of course, will make the final diagnosis as to paralytic poliomyelitis. The term "paralytic" is meant to include any definite muscle weakness or paralysis.

In addition to muscle testing, a clinical and epidemiological record is being made on every reported case of poliomyelitis among children included in the field trials. Laboratory examination of stool and blood specimens are routinely performed. Furthermore, within the limit of study facilities, the families of these patients are being studied to develop more accurate information on the epidemiological spread of poliomyelitis.

Possible Outcomes of Evaluation

We hope, and theoretically expect, that there will be a high degree of correlation between the antibody levels induced by the Salk vaccine and protection against paralytic poliomyelitis; but we do not yet know this for sure. If a low degree of correlation appears in the evaluation studies, we shall have to look anew for the factors that may be responsible for the lack of correlation between the immunologic effect of the vaccine and clinical immunity to paralytic poliomyelitis. We may yet discover that there are more than three immunologic types of poliomyelitis virus, or that there are major immunologic differences among the strains of each type, or that the level of antibodies produced by the vaccine, while sufficient to prevent access of the virus to the central nervous system by way of the blood stream, still does not prevent access by way of nerve pathways.

These factors which might impair the effectiveness of the Salk vaccine deserve brief discussion. There is no denying that there is always the possibility of finding a fourth or fifth immunologic type of poliomyelitis virus, or a substrain of the three already established immunologic types, which may be beyond the range of the antigenic substances incorporated in the Salk vaccine. Indeed, researchers frequently turn up such sport or orphan viruses. However, in a systematic and conscientious search begun in 1949 and still continuing, we have failed to find a fourth immunologic type or substrain of poliomyelitis virus capable of causing paralytic disease. Even if such a type were established, it would probably account for only a small percentage of the cases.

The presence of poliomyelitis virus in the blood stream, that is, viraemia, during the

prodromal stage of the disease has been thoroughly established for man and monkey. However, the possibility has not been excluded that the virus also may reach the central nervous system through extension along nerve trunks. This pathogenic mechanism is still under study. However, even if extension of the virus along nerve pathways is demonstrated, there is still the possibility that central-nervous-system involvement may be prevented by the spill-over of vaccine-induced antibodies from the blood into nerve tissue. This would probably be the case in individuals in whom high antibody titers — titers of 6,000 to 7,000—had been developed.

The possibility of the Salk or any other vaccine being 100 per cent. effective is not to be expected. There will always be some vaccinated individuals in whom, for one reason or another, the average amount of antibody in the blood can never be raised to a level where it will prevent central-nervous-system invasion. If the Salk vaccine or any other poliomyelitis vaccine turns out to be as effective as diphtheria toxoid, from which we can expect 90 per cent. to 94 per cent. protection, we shall assume that we have found an almost perfect vaccine.

The placebo studies being undertaken will enable us to speak exactly of the degree of effectiveness of the vaccine. Thus, for example, if the incidence of paralytic poliomyelitis should turn out to be ten cases per 100,000 population among children who received the vaccine and 100 cases per 100,000 population in the matched control group, who received only placebo injections, we could say that the vaccine was 90 per cent. effective in preventing paralytic poliomyelitis. I caution you, however, that these are only hypothetical figures; we will not know the degree of effectiveness of the vaccine until the evaluation of the field trials has been completed.

Even if the vaccine should prove to be only 50 per cent. effective in preventing paralytic poliomyelitis, it would still be valuable and gratefully accepted by the profession and the public. It has already been demonstrated that the vaccine is perfectly safe, and that untoward reactions to its administration are minimal. Hence, the risk in giving it is slight indeed, less than the chance of acquiring paralytic poliomyelitis.

It has been estimated that in the United States the chance of acquiring paralytic poliomyelitis between birth and age twenty is about one in 153. The chance of getting a serious unfavorable reaction to the Salk vaccine is much less than that, but just how much less we must wait for our final evaluation study to tell us. Hence, we would be justified in using a poliomyelitis vaccine that proved to be only 50 per cent. effective.

The situation here may be held up in contrast to that prevailing with rabies vaccine. We know that a certain percentage of the patients who receive rabies vaccine following the bite of a rabid animal will come down with allergic encephalomyelitis and other reactions. However, since the outcome of rabies infection is practically certain to be fatal, we are willing to take the chance of administering rabies vaccine.

In making a final evaluation of the Salk vaccine, the possibility must also be considered that, in addition to affording complete protection against the onset of paralytic poliomyelitis in a certain percentage of vaccinated individuals, it will also modify the degree of muscle involvement in another significant percentage. As a result of our muscle-evaluation studies, we may well find among vaccinated children who nevertheless contract poliomyelitis that (1) initial paralysis is much less severe than might otherwise be anticipated, (2) that the degree of recovery from the disease is high, and (3) that the amount of residual muscle damage or remaining paralysis is very slight.

At the present, from 12 per cent. to 18 per cent. of persons afflicted with paralytic poliomyelitis are left severely handicapped with a considerable degree of permanent muscle damage.

Again by way of a hypothetical illustration, let us assume that the Salk vaccine proves only 50 per cent. effective in totally protecting against the onset of paralytic poliomyelitis but also, on the premise that the vaccine modifies the degree of muscle involvement, that

only 1 per cent. of the persons who might contract paralytic poliomyelitis are left with any residual paralysis.

Now let us superimpose these figures, which are still pure guesses, on the United States poliomyelitis records for 1953, when approximately 42,000 paralytic cases were reported, of whom about one-quarter, or 13,000 people, were left with some residual paralysis. If a vaccine of the hypothetical effectiveness of our illustration had been available in 1953, we should then have had 21,000 cases of paralytic poliomyelitis, but only 260 patients would have been left with any residual paralysis. Practically speaking, the final evaluation of any poliomyelitis vaccine will be its effectiveness in reducing the toll of residual paralysis resulting from poliomyelitis.

Duration of Immunity

There is one thing that the 1954 vaccine field trials will obviously not immediately reveal, and that is the duration of immunity afforded by the Salk vaccine. Continuing research studies will be necessary to work this out. Dr. Salk has observed a series of patients who first received in May 1953 the poliomyelitis vaccine now being used. There has been relatively little fall in their antibody titers since that time. It will take years to determine finally how long the immunity produced by the initial three-injection series of the Salk vaccine actually lasts. An important clinical question to be settled will be the intervals of time at which booster shots, following the initial series, may be required.

One attempt to get at this information at an early date is being made through an experiment in which a colony of about 100 chimpanzees are being vaccinated with the Salk vaccine. The chimpanzee is an excellent model for study of poliomyelitis in man; it responds to the virus and to vaccination against it approximately like the human subject of the same relative age. Since it will be possible to challenge the vaccinated animals with poliomyelitis virus at intervals, early indications of the duration of immunity may be forthcoming from this experiment.

SUMMARY AND CONCLUSIONS

A large-scale field trial has been undertaken to test the effectiveness of a vaccine against poliomyelitis developed by Dr. Jonas Salk of the University of Pittsburgh. Nearly 500,000 children in the United States, Canada, and Finland have received vaccine injections — with an absolute minimum of untoward reactions. The vaccine is unquestionably safe.

The plan of study and evaluation set up for the field trial will permit exact answers to the questions: "To what extent does vaccination protect against paralytic poliomyelitis under natural conditions of exposure?" and "Exactly what kind of protection does the vaccine offer?"

It is possible that the vaccine will offer complete protection against paralytic poliomyelitis to a high percentage of vaccinated children. It is also possible that the vaccine, while not offering complete protection against paralysis, will nevertheless modify the course of the disease to the extent that residual paralysis will be greatly reduced.

The final evaluation of the vaccine and its use in the 1954 field trial is being made independently by the Poliomyelitis Vaccine Evaluation Center at the University of Michigan, under the direction of Dr. Thomas Francis. A report is expected in 1955, probably in the spring of the year. These evaluation studies will determine the future use of the vaccine.

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ANSWERS TO QUESTIONS

Question:

DR. VAN RIPER: Dr. Wilson has asked me to elaborate on the so-called "observed" as opposed to the placebo control group under study. There were so many questions raised as to whether we should subject children to three injections of a placebo that it was questionable at one time whether or not we could carry out such a study. At a meeting in New York City attended by representatives of all State Health Departments, a number of men interested in communicable diseases said that they thought a placebo type of study could be carried out. So we have two types of study. The placebo study is a "blind study"; no one knows whether a child has received vaccine or placebo. In the so-called observed control areas, children who volunteered in the second grade, were given the vaccine. Children in the first and third grades are used as controls to determine whether or not there is more or less poliomyelitis among them as compared with the vaccinated group.

Question:

DR. VAN RIPER: The question has been asked whether or not the Salk vaccine is polyvalent. Yes; it does contain equal amounts of all three known types of poliomyelitis virus.

Question:

DR. VAN RIPER: The question has been asked about the use of gamma globulin. This year it is under the direct control of the state health officer and he may use it within his state on whatever plan he determines is best. We have said that, since the effectiveness of gamma globulin in family contacts is indeed questionable, it is hoped and it is almost asked, that in every state it be used in groups above the family level,—that is, in camps, schools, play-ground groups, or where there has been intimate contact. [Hammon's latest reports, however, have tended to resolve this question.] It has been quite definitely demonstrated that by the time the index case appears within a family group, most, if not all, of the members of that family group are already harboring the virus. We are almost convinced today that the appearance of poliomyelitis in a family group is an explosive sort of thing. How it is introduced to the group is questionable. However, there does appear an almost immediate infection within the whole group.

Question:

DR. VAN RIPER: The question about the matter of pooled sera has been asked. If gamma globulin is effective, then certainly the use of collected serum is just a matter of convenience of dosage. By the use of gamma globulin, the quantity injected can be reduced so that it is not quite such an ordeal for the individual receiving it.

Question:

DR. VAN RIPER: That's right. Careful investigation has shown that where pools of blood represent a sufficient cross section of the population and numbers, you will have approximately the same titer of antibody to all three types of virus in that pool.

Question:

DR. VAN RIPER: The question has been asked if this is a killed virus or a live virus. I think that we have now more or less settled on the term "inactivated". At least, safety tests fail to prove any evidence of activity; but whether every last single particle of virus has been killed by formalization is something that no one will say positively. There are researches continuing on attenuated or virus variants of various sorts,—for example, by Dr. Sabin in Cincinnati, Dr. Cox at the Lederle Laboratories, and Dr. Melnick at Yale. However, one always has to worry about such attenuated viruses. Can they revert back to their original virulence in passage in human beings?

Question:

DR. VAN RIPER: I think there is still much that we do not know about the transmission of poliomyelitis and the sources of infection. I think we are almost forced to conclude that, like other virus diseases, it is probably spread from person to person by intimate contact. Very interestingly though, while much work has been done on searching for the spread of virus by fruits and vegetables, a research worker (Syverton at the University of Minnesota) on grant from The National Foundation has demonstrated that virus actually can go up through plants and appear in growing vegetables—of course, under experimental conditions. No one has ever recovered virus from ordinary garden vegetables or fruit or anything else. However, there is still much that we do not know about the epidemiology of poliomyelitis.

(*Continued on page 1019*)

PROGNOSTIC IMPLICATIONS OF ELECTROMYOGRAPHY IN ACUTE ANTERIOR POLIOMYELITIS * †

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In previous investigations, different aspects of the electromyogram have been correlated with the degree of initial paresis and with later recovery in poliomyelitis[3,15]. These studies indicated that the final degree of paresis was determined early in the acute stage of the disease. However, because of the limited patient material, it was considered desirable to repeat the studies on a new group of patients. This was especially indicated because of the improved technique for the recording and analysis of muscle-action potentials and also because it was imperative to follow the force and the functional state of the muscle with grading under standard conditions by especially trained and experienced personnel.

MATERIAL AND METHOD

The subjects were forty-five patients, two to twenty-five years of age, hospitalized with acute poliomyelitis in the Orthopaedic Department of the Children's Medical Center in the summer of 1952.

Electromyographic examination was performed within the first three weeks of hospitalization and, whenever possible, repeatedly in the following two months. Follow-up examination was performed a year later. The records of the initial tests were not available when the final tests were performed.

Most of the patients were children, 90 per cent. of whom were under fourteen years of age (Chart I). One to three affected muscles and, if possible, the symmetrical unaffected muscles were examined. In addition, 130 normal persons, one to forty years of age, eighty-eight of whom were below the age of fourteen, served as controls.

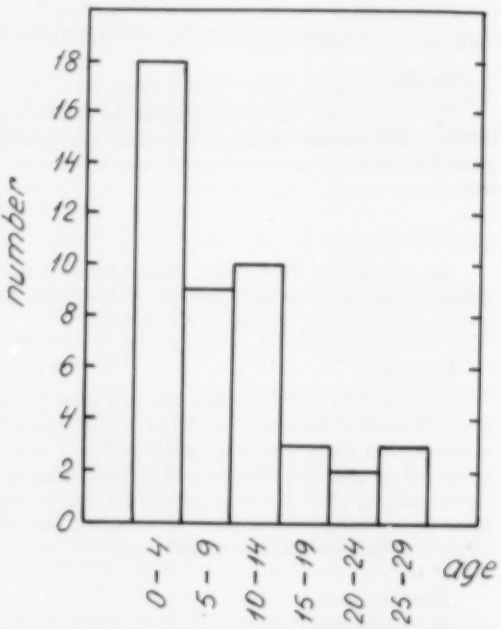

CHART I
Age distribution of poliomyelitic patients.

Estimation of muscle force according to the standard routine of the Children's Medical Center was done by a physical therapist and a physician at the time the first electromyogram was made forty-eight hours after the body temperature had become normal; thereafter, it was done every two

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weeks for the first month, every month for four months, and every two months to the twelfth month, the last estimation of muscle force being done at the time the follow-up electromyogram was made. The reproducibility of the grading was indicated by the results obtained by independent examiners, as well as by the consistency of the findings from time to time.

Muscle grading was performed according to the following scale:

Zero: No palpable contraction;

Trace: Palpable contraction, but not sufficient to produce movement about the joint;

Poor: Contraction sufficient to produce complete range of movement, but not against gravity;

Fair: Contraction sufficient to produce full motion against gravity, but not against added resistance; (The force of such a muscle amounts to about half the force of a normal muscle.)

Good: Contraction sufficient to produce full motion against gravity and some resistance;

Normal: Contraction which can overcome a greater amount of resistance than a *good* muscle and can continue functioning within normal limits of fatigue.

The muscle-action potentials were recorded from three cathode-ray oscilloscopes with a three-channel electromyograph (DISA) simultaneously from three different regions of the same muscle at a force which allowed discrimination of the individual action potentials (single oscillations). Each action potential was photographed five to ten times with a sweep velocity of 50 to 100 centimeters per second and a sweep frequency of 5 cycles per second. The mean values of action-potential duration and amplitude were based on measurements of potentials from twenty to forty different regions of the same muscle. The number of potentials which in the following accompanies the mean value indicates the number of muscle regions from each of which a potential was obtained. The electromyogram was recorded at maximum effort as well, continuous recording at a velocity of five centimeters per second being used. A separate set of three oscilloscopes connected in parallel with those used for recording was used for observation. Moreover, each channel could be connected to a loud-speaker.

The amplifiers were balanced differential amplifiers, with an input impedance of 100 megohms in parallel with 60 micromicrofarads. The noise level was 2 microvolts root mean square, with short-circuited input terminals. The frequency response was linear within 3 decibels from 3 to 10^4 cycles per second. The common mode rejection ratio of amplifier and electrode was 500.

Concentric needle electrodes were used for leading off and were heat-sterilized before each examination. The external diameter of the cannula was 0.7 millimeter, the diameter of the platinum core was 0.1 millimeter, the leading-off area was 0.04 square millimeter, and the tip angle was 16 degrees. The electrode impedance measured with a voltage of less than 10 millivolts was 50,000 to 150,000 ohms at an angle of 45 degrees (150 cycles per second).

The patient was grounded by a flexible metal electrode, five by ten centimeters, which was placed near the muscle under investigation and which was connected to the earth terminal of the amplifier.

The intramuscular temperature was determined before each electromyographic examination by means of an inserted thermocouple (stainless steel-constantan). When the temperature was below normal, it was elevated to normal by means of a heating pad. Under standard conditions, the normal temperature in the brachial biceps is about 36 to 37 degrees centigrade. It decreases in the muscles distal to the brachial biceps, such as the small muscles of the hand[4], to as low as 34.5 degrees centigrade.

TABLE I

FACTORS FOR CORRECTION OF ACTION-POTENTIAL DURATION AND AMPLITUDE FOR AGE AND MUSCLE

Muscle	Duration (In Age Groups)						Amplitude
	1 to 4	5 to 9	10 to 14	15 to 19	20 to 24	25 to 29	
Biceps brachii	1.00*	0.97	0.94	0.88	0.83	0.77	1.00**
Triceps brachii	0.89	0.86	0.84	0.78	0.74	0.69	0.69
Quadriceps femoris	0.89	0.86	0.84	0.78	0.74	0.69	0.44
Deltoideus	0.81	0.79	0.76	0.71	0.67	0.62	0.56
Tibialis anterior	0.81	0.79	0.76	0.71	0.67	0.62	0.68
Gastrocnemius	1.06	1.03	1.00	0.93	0.88	0.82	0.70

* Absolute value of duration 8.2 ± 0.2 milliseconds.
** Absolute value of amplitude 195 ± 2 microvolts.

Definition of Action-Potential Parameters

Duration was measured as the total duration of the action potential, and included both a gradual onset and an extended tail. Action-potential duration varied both with age and with the muscle under investigation; by multiplying with the correction factors given in Table I, all results were referred to the value found in the brachial biceps in the age group one to four years (8.2 ± 0.2 milliseconds, 170 potentials). These correction factors were derived from examinations of the brachial biceps of 130 normal persons, one to forty years of age. For different muscles, the correction factors were obtained partly from the brachial biceps (mean duration 9.5 ± 0.2 milliseconds, 185 potentials), the gastrocnemius (8.9 ± 0.2 milliseconds, 194 potentials), and the tibialis anterior (11.7 ± 0.3 milliseconds, 166 potentials) of five subjects, twenty-one years of age, and partly from the brachial biceps (500 potentials), the quadriceps femoris (344 potentials), and the deltoideus (115 potentials) of ten other subjects, twenty years of age[7].

Amplitude was measured as the peak-to-peak deflection of the action potential, that is, the difference between the extreme positive and extreme negative values. An attempt was made to adjust the amplification so that potentials of different amplitudes were recorded at about the same deflection on the screen. Mean action-potential amplitude does not vary with age, but it is different for different muscles. Therefore, values of amplitude were referred to those found in the brachial biceps. The correction factors for the mean amplitude in different muscles are given in Table I. The amplitude in the normal brachial biceps amounted to 195 ± 2 microvolts (3,800 potentials, 130 subjects).

The *shape* of the potentials was described by the number of deflections across the base line, potentials with five or more phases being denoted as polyphasic potentials. Diphasic and triphasic potentials comprise about 80 per cent. of all potentials recorded in normal muscle[7].

The *degree of activity at maximum effort* was defined according to the following criteria:

Interference pattern: simultaneous activity of numerous motor units, in which the frequency or amplitude of the individual unit discharge cannot be discriminated;

Transitory state: the activity of one or two single units can be distinguished against a background of activity from neighboring units;

Single oscillations: the activity of a single unit is recorded without interference from the responses of adjacent units.

In severe paresis of neurogenic origin, single oscillations are recorded at maximum effort, whereas this is the case only at slight effort in normal muscle.

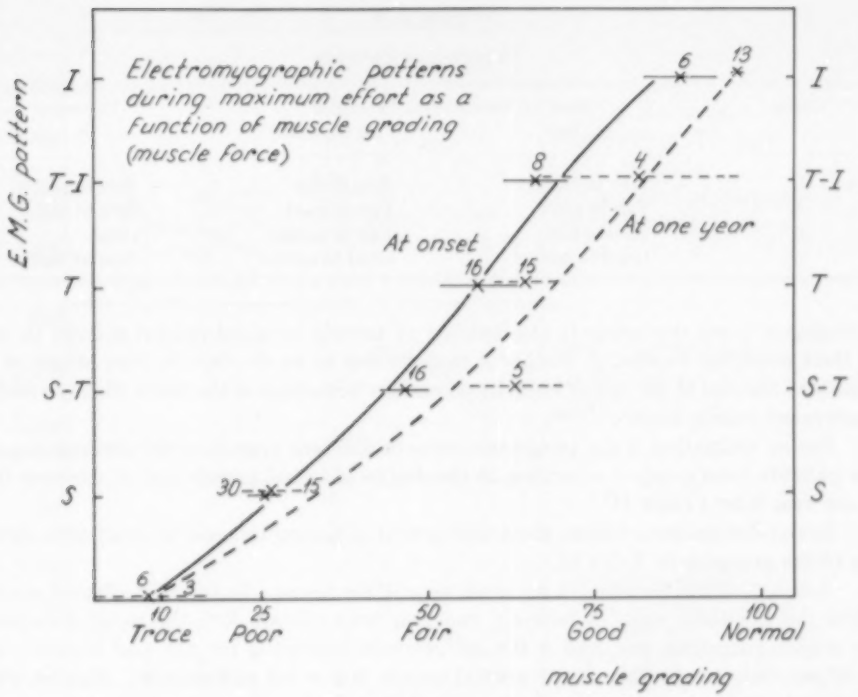

CHART II

Electromyographic patterns made during maximum effort: muscle force in the acute stage of poliomyelitis (————) and one year after the onset (– – – – –). Horizontal lines indicate mean error and the figures denote the number of muscles within each electromyographic pattern. *I*, interference; *T*, transitory state; and *S*, single oscillation.

Abscissa: Muscle grade in terms of percentage of normal muscle function.

Synchronization: The interrelation of discharges in different regions of the same muscle was evaluated by denoting trains of impulses as synchronous when all impulses in one train were coincident with or had a constant time relationship to all impulses in the other train. Two simultaneously recorded leads were considered synchronous when at least one train from one muscle region was synchronous with one train from another. The electrodes were placed triangularly at different depths as far apart as possible (>2 centimeters) in order to decrease the possibility for leading off from the same motor unit. In the previously mentioned normal group (130 subjects), 226 of 1,263 pairs of leads, that is, 17.9 per cent., were synchronous,—a figure which corresponds well to the figures found earlier through the use of an automatic counting device[5].

Denervation potentials: Finally, fibrillation potentials,—that is, spontaneous activity consisting of action potentials with a duration of 1 to 3 milliseconds and an amplitude of 50 to 100 microvolts—were sought in every examination and were recorded whenever found. They did not occur in normal muscle[8]. The measurements of action-potential parameters were confined to potentials found in voluntary activity.

RESULTS

The pattern of the electromyogram made at maximum effort as it appears at low-speed recording is an expression of the number of active units in voluntary effort, and is in fairly good agreement with the grade of muscle force (Chart II). At one year after the onset of the disease, the degree of electrical activity corresponds to a relatively higher (10 to 15 per cent.) degree of muscle force than at the onset. There is evidence that this

TABLE II

GROUPING OF PATIENTS

Group	State of Muscle when Examined		Recovery
	At Onset	At One Year	
R^-	Zero to fair	Zero to fair	Zero to slight
A	Fair to good	Fair to good	Zero to slight
R^+	Zero to fair	Fair to normal	Great
N	Good to normal	Good to normal	Zero to slight

discrepancy is not due solely to the inability of acutely involved painful muscles to work at their potential maximum. Rather it may be due to an increase in later stages of the disease in the size of the motor units by secondary branching of the nerve fibers to include denervated muscle fibers[1,2,17,18,21].

For an estimation of the prognostic value of different aspects of the electromyogram, the patients were grouped according to the degree of initial paresis and of recovery from it one year later (Table II).

In the discussion to follow, the action-potential parameters will be dealt with according to the grouping in Table II.

Action-potential duration in the acute stage of the disease: In severely affected muscles which did not show signs of recovery one year later (Group R^-), the mean duration of the action potentials was 10.5 ± 0.4 milliseconds (corrected for age and muscle), that is, 30 per cent. greater than in the normal muscle (8.2 ± 0.2 milliseconds). Muscles which improved greatly in the course of one year (Group R^+) from a severe initial paresis had normal values of mean action-potential duration (Chart III). The muscles of the R^+ group were divided according to the degree of initial paresis into two groups: one with poor muscle strength (eight muscles) and one with fair muscle strength (seven muscles). Although the degree of initial paresis in the group with poor muscle strength was the same as that in the R^- group, there was no increase in mean action-potential duration. The increase in mean duration associated with a lack of recovery in Group R^- cannot, therefore, be attributed solely to the degree of paresis in the initial stage of the disease. Muscles with a less severe degree of paresis, graded above *fair*, but with no recovery or with slight recovery one year after the onset of the disease (Group A), also had a mean action-potential duration within normal limits. The certainty of the determination is less in this group because of the small number of muscles included.

One year after the acute stage, all affected muscles, independent of the degree of recovery, showed an increase in mean duration which averaged 20 to 30 per cent. (Chart III). In muscles which showed good recovery (Group R^+), the degree of increase in action-potential duration above normal at one year was correlated with the degree of initial paresis. The increase was 40 per cent. above normal (11.2 ± 0.6 milliseconds, 404 potentials) in the initially severely affected, and was 15 per cent. above normal (9.2 ± 0.5 milliseconds, 302 potentials) in the initially less severely affected muscles. The increase in mean action-potential duration was more pronounced in the gastrocnemius than in the tibialis anterior. Similarly, lack of recovery was more common in the gastrocnemius than in the tibialis anterior, in that ten of seventeen gastrocnemius muscles and nine of twenty-seven tibialis anterior muscles were in Group R^-.

The mean action-potential *amplitude* recorded in the initial stage of the disease was within normal limits for all groups. One year after the onset, it had increased significantly by 50 to 150 per cent. for all groups with affected muscles (R^-, R^+, A).

In the acute stage of the disease, there was a relative increase in triphasic potentials at the expense of diphasic potentials in all but the severely paretic muscles which later

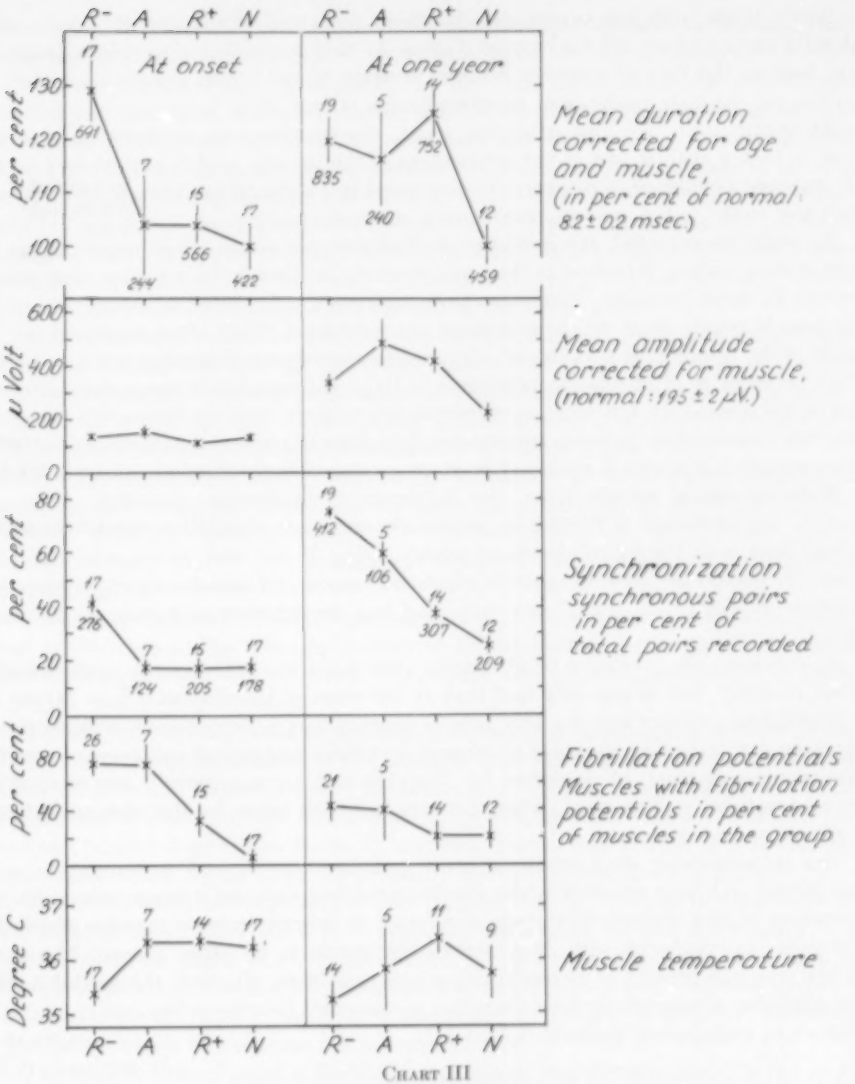

CHART III

Correlation of action-potential characteristics of muscle with degree of initial paresis and later recovery. The vertical lines indicate mean error. The figures above each point denote the number of muscles; the figures below each point indicate the number of different action potentials. In the curve on synchronization, the figures below each point represent the number of pairs of leads.
Abscissa: Muscles grouped according to degree of initial paresis and later recovery (Table II).

did not recover. Moreover, in all groups, *polyphasic potentials* were increased to twice their incidence in the normal controls. One year later, the incidence of polyphasic potentials was slightly higher than that in normal muscle. The increase in polyphasic potentials cannot account for the increase in mean duration; when polyphasic potentials were excluded from the calculation of the mean value, the final result remained unchanged.

In acute poliomyelitis, a high incidence of *synchronization* between discharges in different regions of the same muscle was seen only in severely paretic muscles which did not recover (Group R⁻)—40 per cent. of pairs of leads. The normal incidence of 20 per cent. was found in all other groups: muscles with severe paresis which recovered (Subgroup

R^+, *poor*); those with less severe paresis which recovered (Subgroup R^+, *fair*); those with mild paresis which did not recover (Group A); and in unaffected muscles (Group N). Thus, neither the lack of recovery nor the severity of the initial paresis was solely responsible for the high incidence of synchronization (Chart III).

At examination one year after the onset, the incidence of synchronism was considerably higher than it was in the acute stage of the disease, and it approached normal with increasing evidence of recovery. It amounted to 75 and 60 per cent. in muscles with severe and slight initial paresis, respectively, without recovery.

As might be expected, the *incidence of fibrillation potentials*, which occur during the course of denervation, is highest in the acute stage of the disease (62 per cent. of all paretic muscles). In most instances, fibrillation potentials were only found in one or two of the forty muscle points from which recordings were obtained. They often appeared only as a result of the mechanical stimulus of slight needle movements (insertion potentials). The earliest appearance of fibrillation potentials in these patients was thirteen days after the onset of the disease. In ten muscles examined twice, there were no fibrillation potentials at the first examination (average twenty-one days after the onset), but there were fibrillation potentials at the second examination at an average of forty-three days after the onset.

With increasing muscle force, the incidence of fibrillation potentials decreased. However, the incidence of fibrillation potentials was more closely correlated with later recovery than with the initial degree of paresis, being 75 per cent. in muscles which did not recover and 33 per cent. in muscles which did recover. Of muscles which recovered to full power at one year, only 17 per cent. had had denervation potentials in the acute stage.

At one year, the incidence of fibrillation potentials was still highest in the muscles without recovery, but it was only half that at the onset of the disease (Chart III).

Fibrillation activity was the only type of spontaneous activity found. Neither in the acute stage nor in the later stages of the disease was there any sign of spontaneous activity of the motor-unit type, as described by Watkins and his associates[19], nor were there reflex contractions, or "spasms", when due care had been taken for the adequate placing and relaxation of the muscle.

The *intramuscular temperature* in acute poliomyelitis showed a correlation with initial paresis and later recovery under conditions of bed rest: An average intramuscular temperature of 35.4 degrees centigrade was found in severely paretic muscles which did not recover, as compared with 36.3 degrees centigrade in all other groups. The same tendency was still present at re-examination one year later, although the spread in this and in the other groups was greater than that at the onset because of the lack of standard conditions in ambulatory patients (Chart III).

DISCUSSION

In electromyographic investigations of poliomyelitis, it is well to remember that one is concerned with an investigation of surviving motor units. While loss of motor units may account for certain changes in the electromyographic pattern of the paretic muscle, it cannot account for all. Inasmuch as the characteristics of the action potentials of the surviving units are different from those of normal muscle, there is indication that they too have suffered involvement, or that the loss of motor units is selective.

In paretic muscles, potentials occur with a long duration (almost never found in normal muscle), with a high amplitude (one year after the onset of the disease), and with an increased incidence of synchronism and of polyphasic potentials. These facts justify the assumption that the surviving units have been affected. Confirmatory evidence is the change in neuromuscular transmission during fatigue of affected muscles[3,10,15].

A selective loss of motor units, with survival of those with an especially large number of fibers, could account for the increased action-potential duration and might also explain,

in part, the increase in synchronism. This interpretation follows the concept that the motor-unit potential is the result of the superposition of two components: one derived from the activation of all the fibers of the unit and determining the action-potential duration and the other, a steep potential change, originating from a few synchronously discharging fibers near the recording electrode and determining the action-potential amplitude[6]. The change in amplitude between the acute and the late stage of the disease, however, cannot be explained on the basis of selective loss of motor units. Evidence has actually been presented of a selective destruction of large motor neurons in poliomyelitic monkeys [12,14] and in human patients [11]. However, this does not necessarily imply a selective destruction of large motor units, since Fernand and Young did not find any correlation between the diameter of the axon and the size of the motor unit.

The increased duration is most probably attributable to a decrease in the propagation velocity of the impulse over the individual muscle fiber at an early stage of the disease. It cannot be due to a lack of coincidence of simultaneously activated fibers, since it is independent of the increase in polyphasic potentials and since the potentials of long duration were mostly of the regular diphasic or triphasic shape.

At one year, another factor, which may contribute to the increased duration, is the increase in the size of the motor unit by secondary branching of surviving fibers to re-innervate denervated muscle fibers [2,17,18]. This would increase the average number of fibers discharging simultaneously near the electrode and thereby cause an increase in amplitude as well.

A centrally induced forced interaction between different motor units would likewise cause an increase in the average number of simultaneously activated fibers, including those discharging near the electrode. This could account for the increase in duration, amplitude, and synchronization.

The increase in amplitude at one year was also seen, although to a lesser extent, in the symmetrical normal muscles of the patients. This suggests that the increase in amplitude at one year may be partly due to the presence at this time of secondarily and tertiarily recruited motor units, brought into action during stronger effort than is obtainable in the acute and painful stage of the illness. It is known from normal muscle that the amplitude of potentials which appear after the primarily recruited motor units is higher [13,16].

This study does not confirm previous findings [15] of an increase in amplitude in the acute stage of the disease. There is no apparent explanation for this discrepancy.

The higher incidence of fibrillation found during the present study than that found in the previous study [15] is due to our inclusion of muscles with even very few denervation potentials. If the previously used criteria are applied to the present material, the incidence of fibrillation would be the same (18 per cent.).

The earliest time of onset of fibrillation potentials was thirteen days. In the majority of cases, however, this evidence of denervation appeared between the third and the sixth week. That poliomyelitic muscles behave as other denervated muscles with respect to the occurrence of fibrillation potentials was claimed by Watkins, Brazier, and Schwab, in 1943, and by Watkins and Brazier in 1945.

Evidence as to the correlation between action-potential parameters and clinical features of poliomyelitis has been accumulated in previous studies [3,15], as well as in the present study. In brief, in the acute stage of the disease, prolonged mean action-potential duration, increased incidence of synchronism and of fibrillation potentials, and low intramuscular temperature are found most often in severely paretic muscles which do not recover. The degree of paresis is not the sole responsible factor, in that muscles which have the same severe degree of paresis but which do recover are normal in these respects. Nor is the ability to recover the only factor, since slightly paretic muscles without later recovery are also normal, apart from a high incidence of fibrillation potentials.

This correlation between the action-potential parameters and the degree of recovery

allows prediction as to which paretic muscles can recover. It implies that the eventual outcome of the muscle paresis is largely determined by the degree and type of involvement in the initial disease process.

Certain practical *conclusions* can be drawn from this and the preceding studies. Since eventual recovery of severely affected muscles can be predicted from the early use of electromyography, such examination can help to decide which muscles would and which would not benefit by physical therapy directed to those muscles.

SUMMARY

Action-potential characteristics and muscle force were investigated in forty-five patients in repeated examinations during the initial stage of poliomyelitis and one year after the onset of the disease. The symmetrical normal muscles and 130 normal subjects served as controls.

In order to evaluate the prognostic value of action-potential analysis, the patients were grouped according to the degree of initial paresis and recovery from it one year later, as obtained by muscle grading.

In the acute stage of the disease, *the mean action-potential duration* was increased 30 per cent. in severely affected muscles which did not show signs of recovery one year later (10.5 ± 0.4 milliseconds as compared with 8.2 ± 0.2 milliseconds in normal muscles). Muscles which were equally severely paretic in the acute stage, but which improved greatly in the course of one year, had normal values of mean action-potential duration. Muscles with a less severe paresis but with no or slight recovery had a normal mean action-potential duration. One year after the acute stage, all affected muscles, independent of the degree of recovery, showed an increase in mean duration of approximately 20 per cent. above normal.

There was a considerable increase in the incidence of polyphasic potentials in the acute stage of the disease. This increase could not, however, account for the increase in mean action-potential duration.

The mean action-potential amplitude recorded during the initial stage of the disease was within normal limits (200 microvolts) for all groups and was increased by 50 to 150 per cent. one year after the onset without correlation to the degree of recovery.

Fibrillation potentials (spontaneous low-voltage activity of short duration) occurred in 62 per cent. of all paretic muscles in the initial stage and in 35 per cent. one year after the onset of the disease. The earliest sign of denervation was found thirteen days after the onset of the disease. In acutely paretic muscles which later recovered slightly or not at all, fibrillation potentials occurred more frequently (75 per cent.) than in severely paretic muscles which showed good recovery (33 per cent.).

Synchronous activity between different leads in the same muscle was clearly correlated to the degree of recovery. It occurred in 40 per cent. of paired leads in severely paretic muscles which did not recover, examined in the acute stage, as compared with 20 per cent. in the other groups and in normal controls.

In the initial stage of the disease, the thermo-electrically measured *intramuscular temperature* was significantly decreased (0.9 degrees centigrade) in severely affected muscles without recovery, as compared with the other groups and normal controls. One year later there was a similar tendency.

The finding of a correlation between muscle action-potential characteristics on the one hand and degree of recovery on the other indicates that the eventual outcome of the muscle paresis is largely determined by the initial disease process. Early electromyography may thus provide a guide as to which muscles will and which will not benefit by physical therapy directed to those muscles.

NOTE: Acknowledgment is made to Prof. William Green and to his staff, especially Dr. David Grice and Miss Shirley M. Cogland; without their helpful cooperation, both in the initial examinations and in the

follow-up examinations, this study could not have been carried out. Our thanks are also due to Mrs. Cleo Hertz for her unstinting technical assistance and to Poul Rosenfalck, M.Sc., for his invaluable assistance with the statistical treatment and the interpretation of the results.

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DISCUSSION

Dr. William Green, Boston, Massachusetts: It was our great good fortune to have had Dr. Buchthal and his associates from the Neurological Institute of Copenhagen in our Department while this work was being performed. This investigation was started in our laboratory by Dr. Helge Hertz who was on a special Research Fellowship from The National Foundation for Infantile Paralysis. Tragically, he became ill while here in the United States and died. His passing was a great loss; he was a most capable investigator, a scholar, and a gentleman. Dr. Buchthal and Dr. Madsen came over to finish this work. It was a stimulating experience for us and for our Department, and I wish that we could have kept them permanently.

The objective of the investigation by Dr. Buchthal and Dr. Madsen,—namely, to be able to prognosticate accurately in the early stage the future function of a muscle affected by acute poliomyelitis—is certainly

(*Continued on page 1013*)

DIGITAL ARTHROPLASTY OF THE PROXIMAL INTERPHALANGEAL JOINT *

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In a highly motile organ such as the hand, a stiff finger is a great disability. Over the years, surgeons interested in problems of reconstruction of the hand have attempted to devise methods for returning motion to ankylosed joints. As experience enlarged, with a greater number of patients operated upon and followed for longer periods, certain impressions were evolved. The ankylosed or deformed metacarpophalangeal joint of the finger could be mobilized by an arthroplastic surgical procedure. With variations, the basic method was the same. MacAusland and MacAusland were early advocates of this procedure. More recent publications by Bunnell, Fowler, and Liebolt have pointed out the value of metacarpophalangeal arthroplasty.

This paper will discuss the problem of deformity in fingers caused by an ankylosed proximal interphalangeal joint in an awkward or deformed position. Little or no enthusiasm has been shown for arthroplasty of the proximal interphalangeal joint. The results have been far below those obtained in the metacarpophalangeal joint. Surgeons have been advised that it is preferable to amputate or arthrodese the digit in the flexed position of function[2]. One author[14] categorically stated that digital arthroplasty should not be used to repair ankylosis of the interphalangeal joint. It would seem that a thorough review of arthroplasty of the proximal interphalangeal joint might be helpful to surgeons interested in restoring useful motion to the fingers.

There are relatively few reports in the literature on the use of arthroplasty in the proximal interphalangeal joints. It would be rather difficult to designate any one surgeon as having first devised this procedure. There is no doubt that actual surgical experience far exceeds that reported in publications. An early report was made by Payr in 1914. Using an interposed flap of fatty tissue, he obtained a painless joint with good motion in two patients. In a well illustrated case of a sixteen-year-old cadet, motion was produced in the ankylosed proximal interphalangeal joint of the middle finger of the right hand. Gallagher obtained a good range of painless motion in the proximal interphalangeal joint of the fourth finger, left hand. Traumatic bony ankylosis had been present. No mention is made of the method used. Hamilton obtained motion in the deformed proximal interphalangeal joint of an index finger. He interposed fascia with fat attached. MacAusland and MacAusland quoted Schupatschoff, who discussed the results obtained by Russian surgeons during World War I. Although no statistics were given, it was said that the use of interposed fascia was the most successful method. Lexer returned motion to a rigid, extended middle finger in an amateur violinist. He constructed an arthroplasty of subcutaneous tissue in a deformed proximal interphalangeal joint. Hesse has written one of the best papers on this subject. He obtained both good and bad results in fourteen cases. An interposed lining of fascia or periosteum from the tibia was used in the reconstruction of the joint. Brocq attempted an arthroplasty in the middle joint of the third digit without success. Fascia was used. The use of interposed fat was favored by Kanavel in a single case. MacAusland and MacAusland constructed a fascial joint to return motion to the digit of one patient. Koch used several methods in attempting to return motion to the proximal interphalangeal

* Read at the Annual Meeting of the American Society for Surgery of the Hand, Chicago, Illinois, January 22, 1954.

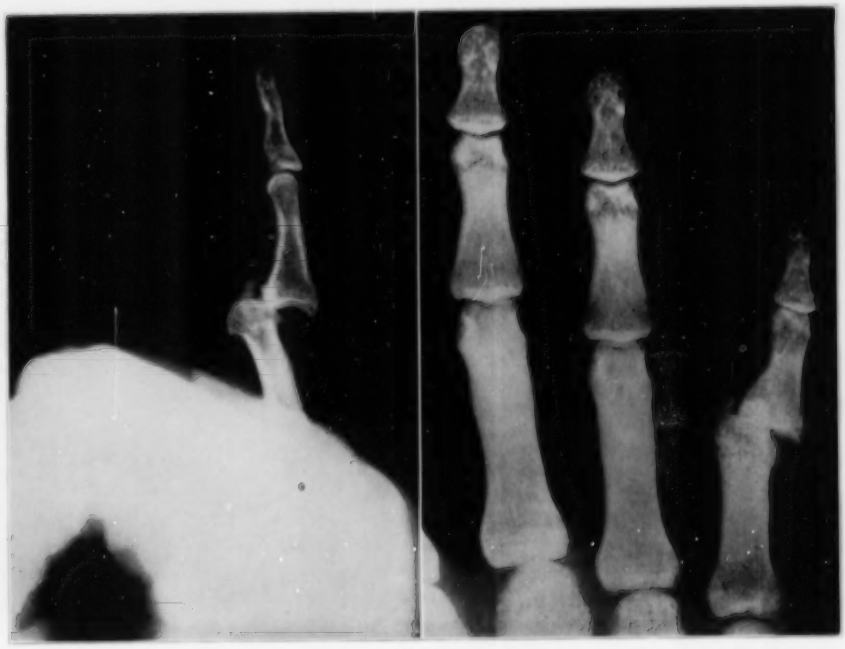

FIG. 1

Unreduced fracture at the base of the middle phalanx, fifth finger. There is also a posterior dislocation at the proximal interphalangeal joint. This deformity had been present for six months.

joints. The results were found to be "discouraging". Burman inserted a Vitallium cap on the distal head of the proximal phalanx in the middle finger. Marked lateral instability was found to exist. Burman and Abrahamson next reported a case in which a lucite cap was used. Useful grasp was present, although there was some tendency toward ulnar deviation. Kestler employed joint resection in returning motion to an arthritic finger in two instances. An excellent paper was presented by Guilleminet, Roy, and Andrie in which four patients showed a long period of usefulness at final evaluation. It will be seen that approximately thirty-five examples of arthroplasty in the proximal interphalangeal joint are the basis for statements regarding the value of this procedure. In general, the experience of any one surgeon consists of a very few cases.

SOURCE OF CLINICAL SUBJECTS

For this study, the authors have elected to present their first thirty cases of arthroplasty in the proximal interphalangeal joint. Fifteen patients are from civilian life. This includes the private patients from the practice of one author (R. E. C.). It also includes ward patients from the Hand Service of the New York Orthopaedic Hospital at the Columbia-Presbyterian Medical Center. The remaining fifteen patients were treated on the Hand Service at the United States Naval Hospital, St. Albans, New York. In this division, all patients were members of the various branches of the Armed Forces. The ages of the patients ranged from eighteen to fifty-nine years. It is also of interest to note that all patients were males. In all cases, both the metacarpophalangeal and the distal interphalangeal joints were mobile. The evaluations for this paper have been made at periods ranging from six months to seven years following operation.

CRITERIA FOR OPERATION

The preoperative evaluation of the problem in the treatment of ankylosed digital joints is the most important step. We wish to make this point with great emphasis. There

FIG. 2-A

FIG. 2-B

Fig. 2-A: Fracture-dislocation at the proximal interphalangeal joint has given a marked deformity, with 15 degrees of recurvatum.

Fig. 2-B: Use of the entire hand is limited by the protruding digit. Only a few degrees of motion can be produced by the tendons which have not been damaged.

is no doubt that digital arthroplasty has fallen into disrepute because of poor evaluation of the prospective joint problem. In the proper selection of the patient who might greatly benefit from an arthroplasty, we have three major considerations.

1. The deformity of the finger must be great and the joint must be in an awkward position. We feel that a digit with ankylosis of the proximal interphalangeal joint in the flexed position of function is not suitable for digital arthroplasty. Our patients have all presented marked deformities about the proximal interphalangeal joint. Ankylosis in full extension or even recurvatum has been frequent. We have been able to help to correct the problem of a fixed flexion deformity at an angle of 90 degrees or more. In addition, many of these deformed joints presented a list to the radial or ulnar side of the hand.

2. It is absolutely necessary that the tendons surrounding the joint have not been injured. The type of injury must be understood, if the probability of motion is to be evaluated. If old extensive infection has caused the collateral tendons to adhere, the case would not be suitable for arthroplasty. The surgeon should avoid the temptation to attempt an arthroplasty in a joint which has been immobile for too many years. Proper evaluation in such a case may be impossible.

3. The most difficult consideration is that of patient motivation. The desire of the patient for the return of motion must be high. His cooperation in the postoperative plan is extremely important. This is especially true whenever the return of motion is the goal. If there is doubt that the patient will show a high degree of effort, it would be more desirable to select arthrodesis as the method of reconstruction.

The majority of patients in our series were disabled by fractures at the base of the middle phalanx (Figs. 1, 2-A, and 2-B). In some, fibrosis from dislocations or penetrating sharp objects had caused immobility. Infection had also produced ankylosis. Exact classification into groups seemed of no value, since many patients had fractures as well as infections. The deformity in all cases was markedly disabling.

FIG. 3-A

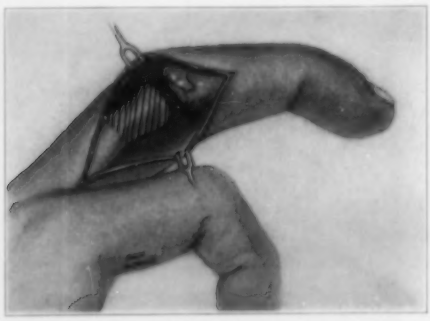

FIG. 3-B

Fig. 3-A: A longitudinal mid-lateral incision is used to expose the damaged joint. This opening is carried directly to the shaft of the proximal phalanx.

Fig. 3-B: Approximately the distal third of the proximal phalanx is removed. This is excised subperiosteally. No attention is given to the damaged base of the middle phalanx.

TECHNIQUE OF OPERATION

The authors feel that the best method for arthroplasty in the proximal interphalangeal joint is also the simplest method. In general, all authors have used some material such as fascia, fat, periosteum, or others, for the lining of a new joint. We have not found this necessary. It demands too much surgical manipulation and exposure. The interposed material may even become necrotic and cause further ankylosis. In addition to fat and fascia [17, 18], both metal [3] and plastic [4] joint coverings have been used. We feel that such a foreign body would be more useful when surrounded by protective masses of vascular tissue.

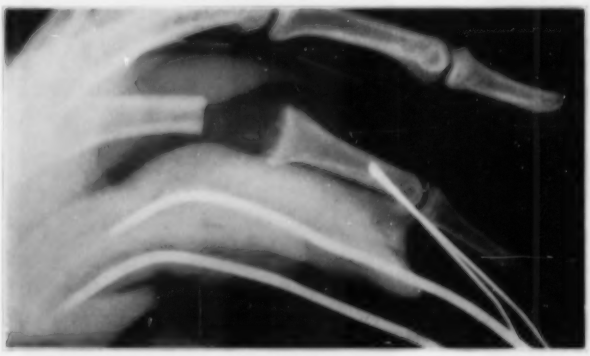

FIG. 4

A Kirschner wire is passed through the middle phalanx for traction.

The surgical approach to the proximal interphalangeal joint is made through a mid-lateral incision. It is carried directly to the distal shaft of the proximal phalanx. The periosteum is elevated from the bone and the capsular attachments are severed. About the distal third, or a little less, is removed from the proximal phalanx (Fig. 3-B). Great care should be taken that the osteotomy line is at a right angle to the axis of the shaft. Angulation of the osteotomy plane produces lateral tilting. Surgical care is never directed to the base of the middle phalanx, even though this may be greatly deformed. The subcutaneous tissues and skin are closed with interrupted sutures. A Kirschner wire is passed through the middle phalanx (Fig. 4). The hand and digits are held in the position of function by a plaster cast which extends over the forearm and wrist to support the digits. An outrigger of wire is incorporated. The Kirschner wire is attached to the wire outrigger with elastic bands. This holds the digit operated upon in the curved position of anatomical rest (Fig. 5).

POSTOPERATIVE CARE

The traction is comfortable if correctly applied. The plaster supporting the digit should be well padded. Traction is maintained for six weeks after operation. In determining

FIG. 5

Traction is maintained by elastic bands for a period of six weeks.

FIG. 6-A

FIG. 6-B

Fig. 6-A: After arthroplasty of the proximal interphalangeal joint, there is frequently loss of extension in the final 10 degrees. The digit is stable and conforms to the functional pattern of the hand.

Fig. 6-B: An excellent grip is obtained as the digit moves painlessly and smoothly through a range of 70 degrees.

this period, we have tried to use no traction, and shorter periods of one, two, three, and four weeks of traction. As our best results were obtained in patients who had had traction for six weeks, this has become our elected routine. The wire can easily be removed and the pin holes have all healed readily. The patient must then enter an active program of mobilization of the digit. Motion under warm water is helpful and the use of paraffin baths is desirable. Occupational therapy helps patients to improve grasp and dexterity.

All patients are urged to massage the digit constantly in flexion and extension. Some patients can tape the reconstructed digit to the adjoining finger during work. This is quite helpful until independent flexion and extension are secured.

CLASSIFICATION OF RESULTS

The results obtained in our patients have been divided into three classes.

1. *Good results* are those in which a useful range of motion has been obtained. This should approximate the range of adjoining digits. Full extension is desirable, but a loss of the last 10 degrees of extension is quite acceptable. The joint should show a range of 55 degrees or more of active flexion. Angulation to the radial or ulnar side should not be present. There must be no stiffness or awkwardness to limit the use of the hand in normal activity.

2. *Fair results* are those in which a shorter range of motion is found. This range of motion may be quite useful and we have found that the result was quite acceptable to the patient. This category also includes any result in which radial or ulnar tilt of the proximal interphalangeal joint with motion is to be found. A patient with full extension and 90 degrees of flexion had to be included in this group because of ulnar tilt in flexion.

3. *Failure* must be acknowledged in a digit which has not been improved by this surgical procedure. In such cases, the angle of deformity is usually the same as before operation. The total length of the digit is less than before operation.

RESULTS OF ARTHROPLASTY

We have been pleased to find that this operation has produced a high proportion of patients with improved digits (Figs. 6-A and 6-B). In order that the factor of motivation, or perhaps compensation, might be correctly evaluated, we have separated the results of civilian and military patients.

	Military	*Civilian*
Good	6	10
Fair	5	4
Failure	4	1
Total	15	15

Patients with a good result have been very pleased. Of the nine patients with a fair result, six were pleased and three expressed some dissatisfaction. One patient was distressed by the ulnar tilt or angulation which occurred in flexion of the digit. One patient disliked the shortened appearance of the fourth digit. The third patient was disappointed in the resulting range of motion. In reviewing the fair results, the authors felt that in some of these cases a better result could have been obtained if more bone had been resected at the time of operation. Five patients were not improved by this operation. In three cases, an inadequate amount of the distal portion of the proximal phalanx had been resected. The other two failures resulted from improper preoperative evaluation of the power and mobility of the tendons. One finger remained shortened in the preoperative extended position. The other digit was quite unstable and interfered with the use of the hand. This digit, a fifth finger, was later amputated. It is interesting to note that not one of the patients wished that arthrodesis had been selected as a method of reconstruction. No patient with a fair result or a failure wished to have the digit arthrodesed in the flexed position of function at a later date.

It is generally believed that this operation produces an unstable digit. In our experience, this has not been the result. The reconstructed digit has improved the function of the hand. In active motion, it gives no sign of disabling instability. This is true in any digit from the index to the smallest digit (Fig. 7). We have not used this method in the thumb. Passive lateral instability may be, and usually is, present to the examiner's grasp. Firm direct pressure by the reconstructed digit to any degree is impossible. In the average

daily use of the hand, however, there is relatively little need for this one activity. Most patients automatically substitute the adjacent digit for pressure.

Not all case histories are needed to amplify the problem of reconstruction. The following are presented as examples:

CASE 1. M. R., a radio operator, thirty-four years old, had received an injury to the fifth finger while playing baseball six months prior to admission. Roentgenograms revealed a small fracture at the base of the middle phalanx and a dorsal dislocation of the joint. No treatment for this had been successful. As a result, the fifth digit assumed a disabling position in extension.

Examination on admission showed the fifth finger to be rigid in full extension because of an immobile proximal interphalangeal joint. There was ulnar angulation of 20 degrees as a result of this joint deformity.

Arthroplasty was performed at the proximal interphalangeal joint. Traction was maintained for six weeks. After removal of the Kirschner wire, a regimen of active exercise was outlined. Eleven months later, final evaluation demonstrated an excellent functional range. Extension in the last 10 degrees was not present. The active range of flexion was 70 degrees. The tip of the digit touched the palm. No instability was found in daily use and even the ulnar deviation had been corrected.

FIG. 7

Two years after arthroplasty even the fifth digit was quite stable. The reconstructed joint has maintained an excellent range of motion.

CASE 2. J. P., a watchman, fifty-nine years old, had injured the third digit in an automobile accident twelve months prior to examination. Fragmentation of bone was demonstrated at the base of the middle phalanx. After splinting, the digit became stiff and awkward in an extended position. It was suggested to the patient that the digit be amputated.

Examination of the third digit demonstrated the disabling extended position in grasp or other use. Complete extension in the final 25 degrees was not possible. Flexion from this position was limited to 10 degrees. The roentgenogram showed the base of the middle phalanx to be enlarged and deformed as a result of fracture.

After arthroplasty at the proximal interphalangeal joint, traction remained in place for six weeks. The return of motion was slow. Although the patient was cooperative, a large amount of effort was expended in regaining function. The final result demonstrated the need for a closely supervised postoperative period. The digit no longer protruded awkwardly in grasp. A good range of 170 to 100 degrees was present twenty-nine months after operation and the tip of the digit could touch the palm.

CASE 3. J. W., a sixteen-year-old student, received an infection in the proximal interphalangeal joint of the index finger of the right hand, as the result of a tooth laceration during a street fight. The infection was controlled, but an ankylosed joint remained, with loss of extension in the final 15 degrees. Minimal flexion from this position was present in a range of 5 to 10 degrees.

A simple arthroplasty was performed at this joint eight months after the last evidence of drainage had been observed. After the six weeks of skeletal traction, an active program of rehabilitation was undertaken. When he has seen six months after operation, the patient was working full-time in a meat market, using the repaired digit without limitation. Complete extension was present. Flexion to 80 degrees was possible.

CASE 4. G. M., a clerk, thirty-one years old, had injured the proximal interphalangeal joint of the right third digit in a fight four years prior to surgery. Several small fragments were present at the base of the middle phalanx. Infection had also been present for five months. The digit was quite awkward in grasp. Ulnar deviation of 20 degrees was present. Extension was lost in the final 15 degrees. Flexion from this position was present through 20 degrees.

After arthroplasty and six weeks of traction, motion increased rapidly. However, the osteotomy had not been made at a right angle to the axis of the phalanx and this obliquity produced an ulnar tilt which has persisted. The motion was excellent through a range of 85 to 90 degrees. Because of the ulnar tilt, however, this case was considered a fair result.

CONCLUSIONS AND SUMMARY

There is a definite value in a surgical arthroplasty for the ankylosed proximal interphalangeal joint. The existing literature does not give an adequate evaluation of the procedure and its results, and the reported series have been small. As an aid in the problem of the stiff and deformed finger, the knowledge gained from thirty cases has been outlined. The longest period of follow-up has been seven years. The disabling factors have been fracture, dislocation, and infection at the proximal interphalangeal joint.

Arthroplasty has been found valuable as a method of reconstruction for deformities of the proximal interphalangeal joint in selected cases. No attempt has been made to replace the use and technique of joint arthrodesis in the flexed position of function. Criteria in the selection of cases must include: (1) ankylosis in a position of great deformity; (2) no damage to the tendons which produce motion at the middle joint; and (3) a high degree of motivation in the patient to regain mobility. The most simple technique, consisting in resection of the distal portion of the proximal phalanx, has been used. It is not believed necessary to use interposed tissue, metals, or plastic material for the formation of the new joint. Skeletal traction has been maintained for six weeks. An active, closely supervised program of rehabilitation has been found necessary. In the authors' first thirty patients, there has been improvement in 83 per cent. They hope to report better results in the future.

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DISCUSSION

Dr. Radford C. Tanzer, Hanover, New Hampshire: I am happy that Dr. Carroll has brought up for discussion the problem of digital arthroplasty of interphalangeal joints. I have felt for some time that there is a real need for reconstructive procedures for these joints. Three months ago I carried out my first, and so far my only, digital arthroplasty. A boy of sixteen years had an injury almost identical to that presented by Dr. Carroll. This was a badly comminuted fracture of the proximal aspect of the middle phalanx, with partial subluxation dorsally of the middle phalanx on the proximal phalanx. The patient came in with a finger which was stiff in a position of extension and requested amputation. I made a U-shaped flap with the base directed proximally to expose rather widely the dorsum of the fractured joint; the fragments were reduced, the comminuted bony material was removed from the dorsum, and the middle phalanx was beveled to furnish a concavity which had more or less the same contour as the articulation of the proximal phalanx. Antebrachial fascia removed from the forearm was used as a lining for this denuded bone, being spread across the surface by several catgut sutures which were brought out through the skin in four quadrants. Fixation was obtained by a single Kirschner wire, the joint being held in a position of 50 degrees of flexion. After two weeks the Kirschner wire was removed and motion was started. When I last saw him, ten days ago, he had about 37 degrees of painless motion and the joint appeared stable. He did not have complete extension of the finger. This was due to disruption of the central slip of the extensor tendon on the middle phalanx at the time of injury, which I did not correct. If I had a similar case, I would create a small slip from the extensor aponeurosis and attach it to the middle phalanx in the hope that the patient would regain full extension.

Dr. Carroll and Dr. Taber are to be commended on directing our attention to the possibilities of mobilizing rather than arthrodesing badly damaged interphalangeal joints.

Dr. Sterling Bunnell, San Francisco, California: The injured middle finger joint has always presented a problem. We have partly solved this by an arthrodesis of the joint in semiflexion and shortening the finger somewhat, as a stiff finger is in the way and a short finger is not in the way. Arthrodesis gives stability and freedom from pain. The amount of flexion into the palm through the proximal and distal joints is sufficient to get the finger out of the way in flexion of the hand. That has been our main resource in stiff finger joints.

Dr. Carroll brought out two points. He produces a large gap between the bone ends and he applies traction for six weeks. These two factors are sufficient for obtaining good motion, full extension, and very good flexion. He is to be congratulated on his results.

Dr. Carroll told me that stability in these fingers was good except in extension. Naturally, one would not expect good stability, because there are only two tendons, one in the back and one in front. An arthroplasty of the proximal joint gives excellent results, because five or six tendons surround the joint and thus provide stability. Of course, in grasping, the joint is under tension and is then stable, so that additional stabilization is not needed. My only question is how stable the joint will be when the finger is straight. I am glad to see any improvement in the treatment of the stiff proximal interphalangeal joint.

Dr. William H. Frackelton, Milwaukee, Wisconsin: Dr. Carroll has limited his consideration chiefly to the proximal interphalangeal joint of the finger. I would like to add that a satisfactory arthroplasty can also be done at the distal joint in children. On two occasions of primary injury of the distal interphalangeal joint, resection arthroplasty was selected in the belief that, because of the regenerative powers of the child, a satisfactory joint surface and capsule would be formed. Postoperative immobilization was accomplished by a Kirschner wire driven through the distal phalanx into the middle phalanx and left in place for three weeks. A mobile distal joint resulted. A secondary operation of arthroplasty at the distal interphalangeal joint of another child also yielded a good result. I have had no personal experience with arthroplasty at the distal interphalangeal joint in adults.

Dr. Robert E. Carroll (closing): We would like to thank the discussors for their kindness. I think Dr. Tanzer is to be congratulated on his case. He has used a classical method for this type of repair. It will be interesting to see what the end result will be in obtaining full strength both from the interposition of material and after union of collateral tendons.

In the paper presented we selected one joint. We did not consider the distal joint. I think Dr. Frackelton has produced excellent results in this type of case. We have seen a few such cases, but not enough to evaluate the method.

We undertook this investigation because Dr. Bunnell in his wonderful book leaned rather heavily toward arthrodesis of the proximal joint, with remarks on stability. It is rather a challenge to see what can be done in such problems. We found that we did not want to replace the arthrodesed joint, which produces excellent function. Arthroplasty is only one of the steps which may be helpful in certain selected cases.

Stability in these fingers has been good. We have reviewed all four fingers and tested them. Not many people are going to test their child's fingers by direct lateral angulation to see whether they are stable. It is how the fingers may be used in function that is important. We have a method by which we think that digital deformity can be corrected for better function.

ADVANTAGES OF THE KNEE DISARTICULATION OVER AMPUTATIONS THROUGH THE THIGH *

BY COLONEL JOSEPH W. BATCH, COLONEL AUGUST W. SPITTLER, AND CAPTAIN JAMES G. MCFADDIN, *Medical Corps, United States Army*

From the Orthopaedic Service, Walter Reed Army Hospital, Washington, D. C.

Disarticulation at the knee joint has been periodically extolled as the procedure of choice over amputations through the thigh.[2,3,5,12] Convincing arguments and statistics have been presented to support this view, but the procedure has not been generally accepted because of the belief that the stump is unsightly and that the prosthesis is difficult to fit, and because of lack of experience with the procedure. Our first knee-disarticulation stump was fitted because the patient had refused further surgery. This patient walked so well and had so few complaints that it was decided to perform more disarticulations at the knee rather than to amputate at a higher level. Our belief that this level of amputation can be very favorable has been strengthened with each additional case. Although our series is small and the follow-up period is too short for final evaluation, we believe that the procedure deserves more consideration than it has received.

HISTORY

Before the era of modern surgery, amputations were limited to cases of gangrene. Because of the fear of hemorrhage and inability to control it, the earliest types of amputations were confined to disarticulation of joints as described by Hippocrates in his chapter on articulations.

As the means of controlling hemorrhage became perfected, many surgeons began performing amputations through living tissue in cases of trauma and diseases other than gangrene. Even then amputations through joints were still frequent, however. Fabricius Hildanus is credited with performing disarticulations at the knee joint as an elective procedure in 1581. Since then many surgeons have recommended variations in the surgical procedure.[5]

Nathan Smith reported what is believed to be the first American case in 1825. Velpeau is credited with introducing into modern surgery amputation through the knee joint. He reported fourteen such cases. In 1830 he described an operative technique in which the circular cuff closed in the sagittal plane was used.

Other surgeons have reported additional cases and have advocated knee disarticulation as an excellent method of obtaining a satisfactory end-bearing stump.[1,2,4,5,8,9,10,12]

In 1871, G. A. Otis reported 189 knee disarticulations performed during the War between the States with a 56.6 per cent. mortality as compared with a mortality of 53.8 per cent. in 6,229 thigh amputations.

In 1940, Perry Rogers reported on knee disarticulation. He emphasized the advantages of the procedure, refuted previous objections to it, and recommended a modification of the operative procedure whereby the patella was ankylosed to the distal end of the femur.

During World War II, Alldredge was encouraged by the results he obtained from knee disarticulations performed in amputation centers of the United States Army.

INDICATIONS

Although a below-the-knee amputation should be provided if possible, we believe that,

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 27, 1954.

whenever natural knee motion must be sacrificed, the next procedure of choice is a disarticulation at the knee.

The indications for disarticulation at the knee are the same as those for obtaining end-bearing stumps in the thigh. These include congenital anomalies, malignancy, severe trauma, infection of the bones or soft tissues of the leg, septic arthritis of the knee, and an unserviceable below-the-knee amputation stump in which the knee cannot be preserved. Gangrene of the foot and leg is a major indication for knee disarticulation, the only condition being that adequate viable skin must be available for stump closure. Knee disarticulation is the quickest, safest, and least traumatic procedure available.

TECHNIQUE

A variety of incisions to obtain flaps for the knee disarticulation have been described—the posterior flap of Hoin, the larger anterior flap of Brasdor, the circular cuff of Velpeau, the single anterior and double posterior flap of Pancoast, the equal anterior and posterior flap of Nathan Smith, the lateral flap of Rossi, and the oval cuff of Baudens and Sedillot.[5,10] Any method which provides adequate coverage of the stump will suffice. A long anterior and a shorter posterior flap, however, place the scar posteriorly and offer the most advantages.

The procedure employed by the authors is as follows:

The disarticulation is performed with a tourniquet whenever advisable. A long, broad anterior skin flap, measuring approximately one diameter of the knee from the lower pole of the patella, and a short posterior flap, one-half the diameter of the knee from the level of the superior surface of the tibia, are fashioned, with the lateral limit of the incision at the level of the tibial condyles. The anterior skin incision is deepened through the deep fascia to the bone. The entire anterior flap is then dissected from the tibia and the adjacent muscle, the insertion of the patellar tendon and the pes anserinus being included with the flap. The capsule of the knee joint is dissected from the anterior and lateral margins of the tibia, so that the knee joint is exposed. The cruciate ligaments and the posterior capsule of the knee joint are dissected from the tibia. The popliteal nerve is identified, pulled down, and divided, and is allowed to retract. The popliteal vessels are clamped low, divided, and doubly ligated with No. 0 chromic catgut sutures. The biceps tendon is separated from the fibula; the amputation is completed through the posterior flap; and the leg is removed. The patella is not removed and is not allowed to become fixed to the condyles by bony ankylosis. The cartilage is not removed from the condyles or the patella.

A synovectomy is performed only when it is specifically indicated. Usually gangrene of the extremity is a contra-indication for synovectomy, because of interference with the blood supply.

The tourniquet is released and all bleeding vessels are clamped and ligated. The patellar tendon is sutured to the cruciate ligaments and the remnants of the gastrocnemius muscle are sutured into the intercondylar notch. Rubber tissue drains are placed in the wound. The deep fascia and subcutaneous tissues of the anterior and posterior flaps are approximated with No. 00 chromic catgut sutures, and the skin is approximated with continuous locked No. 35 stainless-steel wire.

A compression-type dressing is applied and is held in place with a snug, but not tight, elastic bandage of sufficient width to avoid constricting bands; the authors generally use a six-inch bandage. If sufficient skin for a loose closure is not available, resection of the posterior portion of the condyles should be done to avoid the risk of losing the skin flaps.

As a rule, the wound heals quickly and, since shrinkage of the stump is not a factor, a permanent prosthesis can be fitted in about three to six weeks. If primary healing has not occurred at that time, there is no reason for apprehension and reamputation is not necessary, as these wounds will usually granulate and heal without further surgery.

STATISTICAL SUMMARY

Between 1943 and 1945 a total of twenty-two knee disarticulations were performed at Walter Reed Army Hospital because of infected below-the-knee stumps. The wounds were left open. These stumps were later converted to amputation stumps at a higher level. In

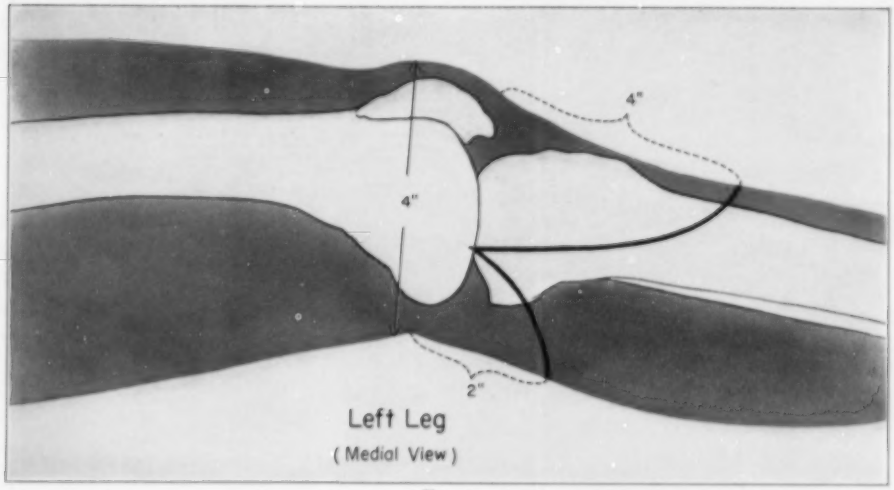

FIG. 1

Outline of skin incisions for disarticulation of the knee. (Courtesy of Armed Forces Institute of Pathology, Washington, D. C.)

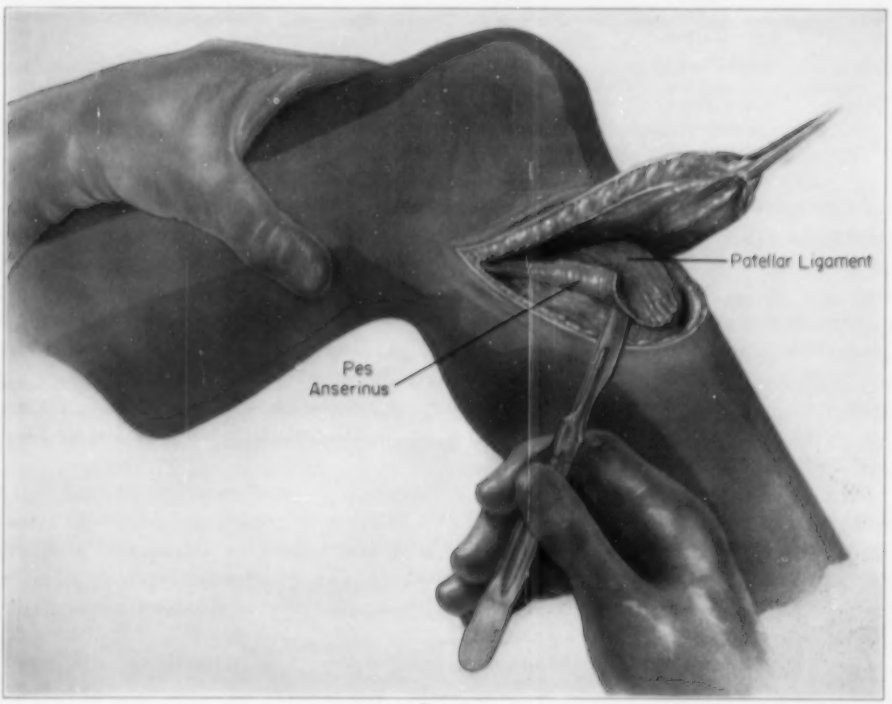

FIG. 2

The drawing demonstrates the elevation of the anterior flap, including the deep fascia with the pes anserinus incorporated. (Courtesy of Armed Forces Institute of Pathology, Washington, D. C.)

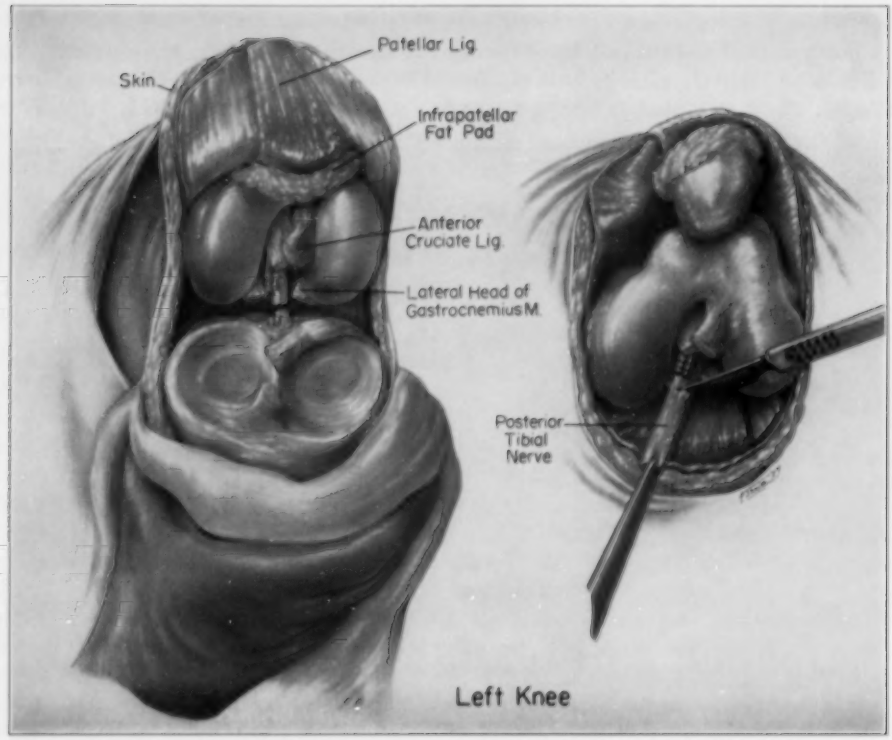

FIG. 3-A FIG. 3-B

Fig. 3-A: Demonstrating the anterior flap after it has been elevated, and the cruciate ligaments, the posterior capsule, and the popliteal vessels and nerves divided. (Courtesy of Armed Forces Institute of Pathology, Washington, D. C.)

Fig. 3-B: The disarticulation has been completed and the posterior tibial nerve has been pulled and divided. (Courtesy of Armed Forces Institute of Pathology, Washington, D. C.)

1950 four similar knee disarticulations were performed. Although these were interim amputations, one patient was fitted with a prosthesis and immediately walked with a good gait and good control of his prosthesis. It was then decided that the other patients should be fitted in a similar fashion. Because of the good results obtained by fitting these interim amputation stumps, it was decided to perform definitive knee disarticulations and to fit the stump with a prosthesis. Since 1950, twenty-eight definitive knee disarticulations have been performed. Six of these were undertaken because of vascular insufficiency and twenty-two because of infection and unsatisfactory below-the-knee amputation stumps. During this same period 195 above-the-knee amputation stumps were treated and each was fitted with a prosthesis.

No attempt was made to fit four senile patients with prostheses; one patient died of coronary thrombosis. Twenty-three have been fitted with prostheses; follow-up studies indicate that, compared with those in the series of above-the-knee amputees, the stumps have withstood prosthetic wear with less irritation. The prostheses have been more enthusiastically accepted and have been worn by the amputee for longer periods of time without discomfort.

No difficulty was encountered in fitting the knee-disarticulation stumps with a satisfactory prosthesis.

Of those patients fitted with a prosthesis, all walked well from the beginning and were able to satisfy the requirements of the walking class at the end of ten hours of instruction

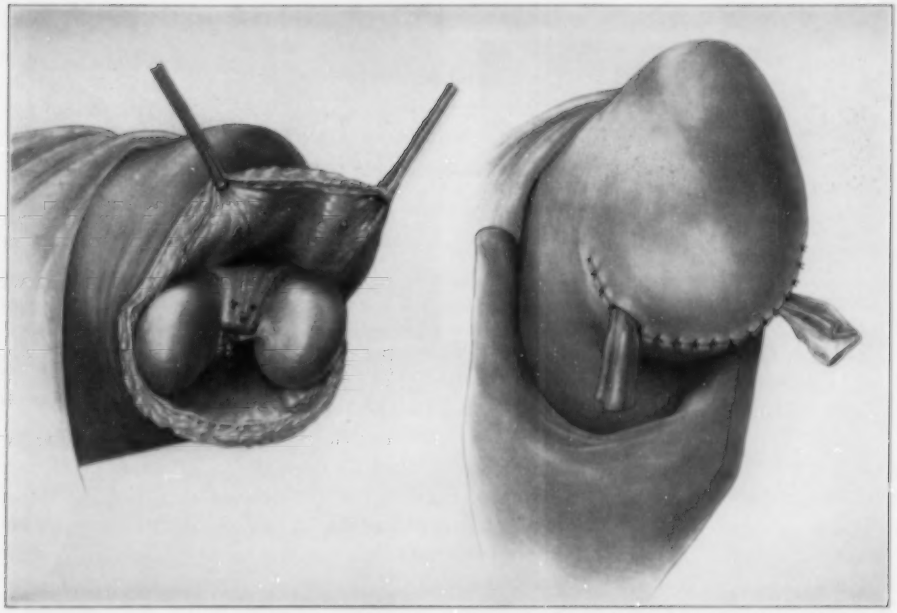

FIG. 4-A FIG. 4-B

Fig. 4-A: The drawing shows the patellar tendon sutured to the cruciate ligaments. (Courtesy of Armed Forces Institute of Pathology, Washington, D. C.)

Fig. 4-B: The disarticulation has been completed and the sutures and drains are shown in place. (Courtesy of Armed Forces Institute of Pathology, Washington, D. C.)

and practice, about two weeks. Patients with other end-bearing stumps required a little over three weeks of training, and those with myofascial types of stumps slightly over four weeks of training to satisfy the requirements of the walking class. Those patients with a knee disarticulation had better balance and gait from the beginning and walked better after training than above-the-knee amputees.

All of the knee-disarticulation stumps have withstood prosthetic wear. These patients were independent economically at an average of eight weeks after surgery, and all were wearing their prosthesis at work for periods ranging from thirty to fifty-five hours per week. They compare very favorably with below-the-knee amputees.

One patient, one of the earliest in this series, whose patellar tendon had not been sutured to the cruciate ligaments, complained that he had a hypermobile patella, an indication for fixation of the patella either by suture of the patellar tendon to the cruciate ligaments or by fixation of the patella to the condyles of the femur, as recommended by Rogers. No other complications have been reported, except for folliculitis on the stumps of two patients. Of the osteoplastic type of stumps, 30 per cent. required revision at a higher level because of stump complications.

ADVANTAGES

The advantages of this procedure over amputations performed through the femur, as cited in 1856 by Markoe and later re-emphasized by Rogers, have been confirmed in this series. The plexus of blood vessels about the knee joint is preserved, thus providing the best possible circulation to the flaps in the thigh. Only the recurrent anterior tibial artery is sacrificed in producing the anterior flap. The popliteal vessels are the only major vessels encountered during the operation, and bleeding in these is easily controlled.

The amputation passes through skin, tendon, and capsular structures. No great

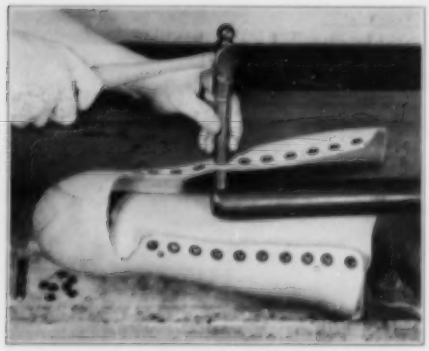

FIG. 5-A

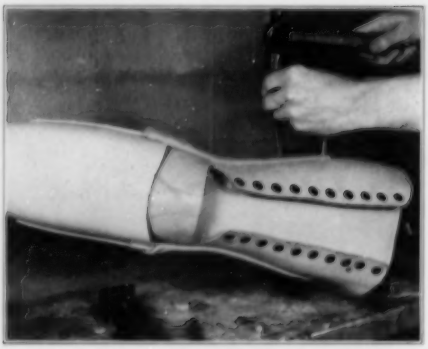

FIG. 5-B

Fig. 5-A: Photograph of molded leather socket for knee-disarticulation prosthesis.
Fig. 5-B: Photograph of the socket being attached to a shin piece by external hinges.

muscle mass is transected, so that the spread of infection through fascial planes is limited. Blood loss is less and shock is minimized. Bone is not divided, so that the barrier of cartilage on the end of the femur assists in preventing the spread of infection through the medullary canal. The muscles which activate the thigh are not divided, so that muscular retraction after healing of the wound is minimal.

A firm, insensitive stump with the widest end-bearing surface in the lower extremity is provided; both the soft tissues of the stump and the bone end are accustomed to pressure and to weight-bearing. Since the function of the thigh muscles is retained, little atrophy results, which allows early fitting of the prosthesis.

The slightly bulbous and triangular end of the stump fits into the socket as a foot into a shoe, and assists both in the control of rotation and in the lifting of the prosthesis. The length of the stump allows extremely good leverage and control of the prosthesis, and an excellent gait is obtained almost immediately. The motion of the thigh is true hip motion and is not a result of pelvic thrust. The patient may kneel on a chair or on the floor in work or play without the prosthesis.

In children the preservation of the distal femoral epiphysis allows continued longitudinal growth of the bone.

It has been stated that prosthetic fitting after this amputation is too difficult, and for that reason the procedure has often been rejected. We believe that an excellent prosthesis can be fashioned for this type of stump as readily as for any amputation through the

FIG. 6-A

FIG. 6-B

Fig. 6-A: Photograph of disassembled multiple-position ankle.
Fig. 6-B: Photograph of kick-stick assembly on the knee-disarticulation socket.

thigh. The prostheses are made in a manner similar to the prosthesis for a Gritti-Stokes amputation.

We use a socket made of molded celastic and leather, with an open-lace front extending to the gluteal fold. External knee hinges are applied and attached to a fiber-wood or metal shin piece. A multiple-action ankle joint is attached to a foot made of willow wood. Knee control can be obtained by the use of an internal kick stick.

CONSTRUCTION OF THE PROSTHESIS

The construction of a knee-disarticulation prosthesis is the same as that used in any plaster-mold technique.

FIG. 7-A

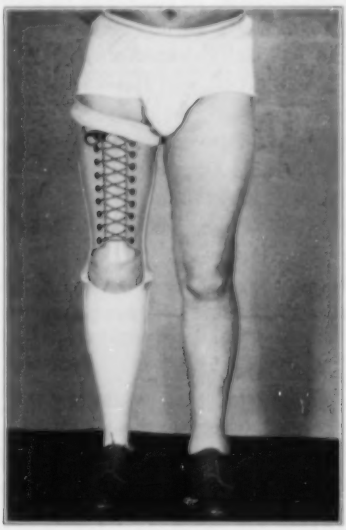

FIG. 7-B

Fig. 7-A: Illustrating the assembled knee-disarticulation prosthesis.

Fig. 7-B: Photograph illustrating the completed knee-disarticulation prosthesis being worn by a patient.

Stockinette is placed over the stump. The mid-line is marked with indelible pencil for later alignment. Prominent areas are also outlined on the stockinette and these markings are transferred to the plaster cast, which is applied next. A light plaster cast is applied to the stump; when this has hardened sufficiently, it is removed. A positive mold of the stump can then be made by pouring plaster-of-Paris into the negative mold, precautions being taken to prevent the plaster from sticking to the negative mold. The positive mold is then smoothed with a file and sandpaper, care being taken to allow the marked-out areas representing prominences of the stump to remain. Cutting and sanding are then carried out, so that the mold conforms to measurements made of the actual stump at various levels. Wet leather is stretched over the positive mold, a triangular flap being made over the distal end of the mold, and this is sewed to leave a smooth inner surface. Celastic, cut to pattern, is then made to adhere to the leather, an additional piece of celastic being placed at the point of the ischial seat, if this is desired. After the celastic has dried, cork is glued to the end of the bucket to bring out the desired contour. An internal kick stick is then fixed to the bucket, with a large plate at the posterior and inferior portion, and the external knee hinges are placed in proper alignment along the sides of the bucket. A thinner piece of leather is stretched over and cemented to the bucket, to give it a finished appearance. The anterior portion of the bucket is then cut out and eyelets are applied to the side for lacing. A leather tongue is formed to fit beneath the eyelets to cover the anterior defect in the socket. The hinges are aligned and attached to a fiber-wood shin piece with a foot and ankle attachment, and the joints are aligned. Final refitting of the socket to the hinges can then be done.

DISADVANTAGES OF THIGH AMPUTATIONS

The higher the level of amputation through the thigh, the more the vascular anastomosis is disturbed. There is a greater loss of blood and the procedure is more shocking to the patient. Muscle bellies retract and lose much of their function. A long time is required to condition the stump, in order to obtain sufficient stability for fitting.

Osteoplastic and tendoplastic procedures provide some of the advantages of the knee disarticulation in retention of muscle and control, but less surface is provided for end-bearing. The prosthesis is not held as securely by the stump, and rotation within the socket of the conically shaped stump is greater. A pelvic belt must be worn after such procedures.

The myofascial types of stumps are subjected to frequent traumata, so that the prosthesis must often be removed. The patient walks with a pelvic thrust rather than with a true coxofemoral gait. The conversion to the new gait requires a longer training period. Although these amputation stumps may be fitted with a suction-socket prosthesis, this type of prosthesis is difficult to fit accurately and often requires many refittings. The patient has difficulty in getting into the prosthesis correctly. At times suction is uncertain and frequently causes "choking" of the stump end, with resultant skin irritation or damage. The prosthesis is somewhat awkward and uncomfortable in the sitting position and patients object to the noise produced by this type of socket.

CONCLUSIONS

Whenever an adequate below-the-knee stump cannot be obtained, a knee disarticulation is the next procedure of choice. The operative procedure is quick, safe, and causes less shock than amputations through the thigh. The circulation in the thigh is preserved, to supply skin flaps which are accustomed to pressure.

Because muscle and bone are not transected, the spread of infection is minimized and the stump heals rapidly. When the patellar tendon has been fixed distally, patellar pain and swelling have not been significant problems. The largest surface available in the lower extremity is provided for weight-bearing. The stump is firm and insensitive. There is less atrophy of the muscles in the stump than after amputations at a higher level and, because of this, earlier fitting of a prosthesis is possible. The shape of the stump provides greater balance and stability without rotation than that of stumps in higher amputations. The patient can walk with an excellent gait almost immediately.

The prosthesis for such stumps is easy to construct and to fit, requires fewer adjustments, and is superior to prostheses for higher levels of amputation through the thigh.

Without a prosthesis the patient can kneel in work or play, bearing weight on the end of the stump in much the same way as the Symes amputee can on his longer stump.

Knee disarticulation as a definitive procedure deserves the consideration of all orthopaedic surgeons.

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DISCUSSION

Dr. S. Perry Rogers, El Paso, Texas: Only those of you who know me very well can appreciate the pleasure it gives me to discuss this paper. I look on the amputation as one of my own creation. In several of my presentations on this subject, I have used the subtitle "A Physiologic Amputation". In this amputation, Colonel Batch and his associates have found an operation that is a good one and have been alert enough to recognize its merits.

Of course I agree with the advantages they have pointed out over amputation through the thigh, and this is specifically true since the development of the suction socket. The latter device is a boon to the unfortunate bearer of the high thigh stump, the sorriest of all. Its adherence to his skin permits him to lift and to rotate his prosthesis with his stump. The ischial tuberosity, after all, is a poor thing to walk on compared to the femoral condyles. The baby rapidly advances from creeping on his buttocks to crawling on his knees. The adhesive principle is as unphysiological as gluing a sandal to the sole of a foot compared to lacing up a shoe. I wish to emphasize that anything a suction thigh stump can do, a knee disarticulation can do better, and longer, and with less discomfort.

I disagree with Colonel Batch in his contempt for the patella. I believe it should be ankylosed to the front of the femur at a level such that its lower pole forms a third bony prominence horizontal with the lower surfaces of the condyles, providing a "three-point landing", so to speak. Most limb makers can relate troubles they have had with "floating" patellae, and I believe that the additional horizontal surface area is worth providing. If my "dovetail-mortise" technique proves difficult, the patella should be anchored in some other way.

My only other criticism of Colonel Batch's technique is a plea not to "pull down" on the popliteal nerve, or on any nerve.

With further experience I have limited my indications for the choice of this site of amputation in my own practice. I no longer attempt it in either diabetic or arteriosclerotic gangrene, regardless of the appearance of the skin available for projected flaps. Gangrene of tissues and infection of bone due to trauma to the leg are a different matter. Circulation in the flaps will hold up following recent embolus at the bifurcation of the popliteal artery, as in rheumatic heart disease in a young patient with otherwise competent circulation. I have performed knee disarticulations, as well as Syme amputations, in which the stumps have retained good function for years in subjects with Buerger's disease sympathectomized before amputation.

Revision of unsatisfactory below-the-knee stumps will produce perhaps the largest group of knee disarticulations.

Congenital amputations and major aplasiae of the leg may seldom get into Army Hospitals, but they form one of the groups in which the results are most rewarding.

The difficulties in obtaining satisfactory prostheses for these stumps are not to be dismissed lightly. The requirements remain as I described them fifteen years ago. Really adequate side joints are not yet commercially available. They must be extremely strong, but not bulky. They must have rigid stops; a back strap may serve to check the motion of extension, but strength and stability of the limb demand massive stops in the joints themselves. Because both the socket and the shin ought to be rigid, they must be sheath joints, for ready assembly and disassembly without the necessity of removing rivets. The socket ought to have a full-length lacing in the front for adjustment and a zipper beside it for everyday use. This prosthesis should have a harness. A fork strap attached by elastic to the top of the socket will extend the knee, as will a kick stick inside the shin, but the wearer can walk farther with less discomfort with a good pelvic harness. The belt should fit low on the pelvis, not around the waist. It should be fastened by a short elastic to the lateral aspect at the top of the socket. Its attachment to the fork strap of the shin by means of a V-shaped elastic webbing provides better balance and folds up better in sitting. I advocate both arrangements, for independent or simultaneous use.

Dr. James E. Bateman, Toronto, Ontario, Canada: As a representative of a group which has long believed in end-bearing stumps, I feel that it is a pleasure and a source of deep satisfaction to discuss this paper. The increased application and acceptance of the Syme amputation in the region of the ankle has been in effect an advertisement for the end-bearing principle. I feel that there is a similar broad field of application in the region of the knee. Our experience with end-bearing stumps in Toronto now bridges two wars, and we

have continued to perform these amputations on our Korean veterans. The advantages of the end-bearing principle from a clinical standpoint are obvious, but possibly it is less well known that there are important advantages from an anatomico-physiological standpoint also, when the amputation is done through the knee by the technique described or by the Gritti-Stokes technique. The profuse anastomosis about the knee is preserved in the flaps. These flaps are superior to either a below-the-knee or above-the-knee amputation.

I agree entirely with the authors on the principles and indications of this amputation. It has been our preference to follow the Gritti-Stokes technique. In the region of the knee, the skin over the patella, conditioned as it has been to wear and tear, naturally forms the best weight-bearing part. The stump which remains after the Gritti-Stokes amputation is small and easily fitted. We have not had complications or difficulties in fixing the patella to the end of the femur. One disadvantage of leaving the femoral condyles is that an oblique weight-bearing surface remains, because of the uneven projection of the lateral condyle. Fixation of the patellar tendon to the cruciate ligaments, as has been suggested, is somewhat precarious; our experience with the Gritti-Stokes amputation indicates that the patella or the patellar tendon must be rigidly ankylosed to withstand the powerful pull of the quadriceps.

On the subject of end-bearing amputations it has been suggested that possibly they cannot be applied on as broad a scale as other amputations in the region. During the past five years at Sunnybrook Hospital we have done sixty-five Gritti-Stokes amputations for peripheral vascular disease alone. These were in patients who were anything but robust. The limbs were gangrenous or gangrene was impending. In reviewing these, it was apparent that we had not lost any flaps, although the amputations were necessary, and there were no fatalities from the complications of the operations. It is apparent that there is a broad field of application for end-bearing stumps in the region of the knee.

Dr. Charles O. Bechtol, Oakland, California: The suction-socket type of artificial limb will not be suitable for knee-disarticulation amputations. The experience with suction sockets generally has been that an increasing number of patients with long end-bearing stumps have rejected the suction-socket prosthesis after two or three years of use and have returned to an end-bearing prosthesis with a conventional pelvic belt. These are amputations of the Gritti-Stokes or the Callander type. The reason for this rejection has been repeated episodes of oedema of the end of the stump or abrasions of the stump against the lower end of the socket. The knee joints and friction mechanisms for long end-bearing stumps are still not entirely satisfactory from the standpoint of durability. The advantages of a long end-bearing stump, however, probably outweigh any disadvantages which may be present.

Colonel Batch (closing): Dr. Rogers may be correct in his claim that the patella needs fixation to the distal end of the femur. We may come to adopt this in time, but to the present time we have not seen the need for it. In our experience fixation of the patellar ligament to the cruciate ligaments has been adequate and results in fibrous ankylosis of the patella to the condyles of the femur. With regard to the zipper arrangement on the socket, it is an excellent suggestion. We have been using it on our Symes sockets.

I agree with Dr. Bateman that the Gritti-Stokes procedure is an excellent amputation and we have used it many times. Nevertheless, I do not believe it is quite as good as the knee disarticulation. The patients do not walk as well as do the knee-disarticulation amputees. With respect to the longer or supposedly longer medial condyle of the femur, I think that is more a theoretical than a practical question, since the socket is molded and the weight is evenly distributed. In roentgenograms of the knees of patients in the standing position, one will see an apparent enlargement of one or the other condyle, depending on whether or not there is a varus or valgus deformity. However, in either instance the tips of the condyles appear to extend down to a plane which is approximately parallel with the floor and with the almost level tibial plateau.

I agree with Dr. Bechtol about the long above-the-knee amputation stumps which are fitted with suction sockets. We have had the same experience; we have to fit some of these patients with suction sockets, however, and I am sure that many would do better if they were fitted with an end-bearing or partial end-bearing type of prosthesis.

THE PATHOGENESIS AND TREATMENT OF DELAYED UNION AND NON-UNION

A Survey of Eighty-five Ununited Fractures of the Shaft of the Tibia and One Hundred Control Cases with Similar Injuries* † **

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Fractures through the dense compact bone of the shaft of the tibia are predisposed to slow healing and non-union. While the over-all incidence of delayed union or non-union has been estimated at less than 3 per cent. for the skeleton as a whole [7, 33], it has been reported in the tibia to be as high as 7 per cent. for selected non-comminuted fractures [41], 9 per cent. for unselected consecutive cases [27], and 75 per cent. for displaced compound comminuted fractures [12]. Statistical reports have given very little information about the basic cause of non-union. Watson-Jones and Coltart, in a classic report on 188 cases, regarded the tibia as an exceptional bone and found that, in attempting to determine the clinical factors responsible for non-union, the permutations and combinations were enormous. The emphasis in the literature in general has been on comparative results of different methods of treatment. The records of at least 10,000 fractures of the tibia from surgical clinics all over the world have been collected and analyzed. The data to be presented in this communication represents an effort to correlate the newer knowledge of the histophysiology of bone repair with the clinical aspects of the problem. The tibia was selected as the bone most suitable for this study because it seemed to offer the greatest challenge to the methods of fracture treatment in use during the period from 1948 to 1953.

Definition of Terms

Delayed union is a term with arbitrary meaning applied in this paper to ununited fractures in which (1) the x-ray examination at any time from four to eighteen months of healing showed inadequate callus and (2) the judgment of the individual surgeon led him to advise a surgical operation to stimulate healing of the fracture.

Non-union is a more specific term, and we have reserved it for ununited fractures in which the roentgenographic examination after eighteen months of healing showed (1) a bone defect, (2) false motion, (3) sclerosis of the bone ends, (4) rounding, mushrooming, or molding of the fracture surfaces, and (5) sealing of the medullary canal with compact bone to form functioning false joint surfaces and an apparent arrest of the process of osteogenesis in the fracture gap.

Newer Theory of Osteogenesis

Observations upon experimental healing fractures recently presented by Urist and McLean [39, 40] form a background for this presentation of the subject of non-union. In both experimental and clinical fractures, bone formation always begins in the fracture site by the proliferation of the periosteum or endosteum at some distance from the line of the

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** These investigations were aided by a grant from the Josiah Macy, Jr. Foundation.

fracture and grows into it by extension from these tissues. The periosteal reaction, wherever it occurs, is intramembranous ossification; the endosteal reaction is appositional bone formation. In both instances, the new-bone formation can be assumed to originate from cells which are linear descendants of osteoblasts. Another form of ossification also appears in connection with healing fractures and is particularly important when a gap must be bridged between the bone ends. The process begins with the formation of fibrocartilaginous tissue between the fracture fragments. The major portion of the mass of cartilage and fibrocartilage appears to differentiate from the periosteum, endosteum, and reticular cells of the bone marrow. Fibrocartilaginous tissue or fibrous tissue is developed in the fracture site, even when the fracture line is microscopic and the bone ends have been compressed by mechanical instruments. Its appearance is the preliminary step in the bridging of the fracture. The process is similar to that seen in foetal osteogenesis. In each case, a cartilage model is first formed from young fibrous tissue and young cartilage cells. New bone grows into the fracture callus from the outside, enveloping and replacing the cartilage by bone.

The function of the cartilage model can be surmised from the behavior of experimental transplants of fibrocartilaginous callus. These display the capacity to produce new bone, not only by proliferation of donor tissue but also from ingrowing perivascular connective-tissue cells of the host which differentiate into osteoblasts by the mechanism of induction. New capillaries are drawn into the substance of the transplanted cartilaginous callus, and bone formation begins as soon as contact has been established between cartilage and young perivascular connective-tissue cells. Induction is generally defined as the physical-chemical effect of one tissue upon another in contact with it. The nature of the inductor and the conditions which favor the induction system for new-bone formation are not known. It is clear, however, that healing of a fracture occurs by the proliferation of the osteogenetic cells of the periosteum and endosteum, by the ingrowth of perivascular young connective-tissue cells which differentiate into osteoblasts by induction, and by a combination of these two processes. The observations to be presented in this paper suggest that non-union results from fibrinoid degeneration in the interior of the callus and failure to establish an effective induction system for osteogenesis to proceed across the fracture gap.

MATERIALS AND METHODS

One hundred consecutive fractures of the tibia which were (1) not entered in the hospital records as instances of delayed union or of non-union, (2) not subjected to any type of bone-graft operation, but which (3) did unite and become available for an end-result examination were reviewed by tabulating (1) type of fracture, (2) measurements of the length of the shaft which had been damaged by the fracture, (3) type of treatment, (4) complications, and (5) healing time. The healing time was the period of time required to regain solid continuity of bone as seen in roentgenograms and to permit full weight-bearing without the aid of a brace or crutches. No effort was made to segregate fractures of the lower to middle thirds from those of any other part of the shaft of the tibia, although it was noted that the lower level was the area in which the reparative process was normally slower to develop and slower to progress.

Eighty-five ununited fractures were reviewed by tabulating the same data as was tabulated for the control fractures which did heal. Additional observations were made upon (1) measurements of the length of the bone defect or pseudarthrosis persisting at the time the patient was advised to have a bone-graft operation, (2) biopsy, amputation, or autopsy specimens of the tissue in the area of pseudarthrosis, and (3) the postoperative healing time required to produce union. The gross structure of the tissue was examined by fresh dissections and roentgenograms of cross sections and sagittal sections of callus and bone ends. The tissues were prepared for microscopic examination by methods used

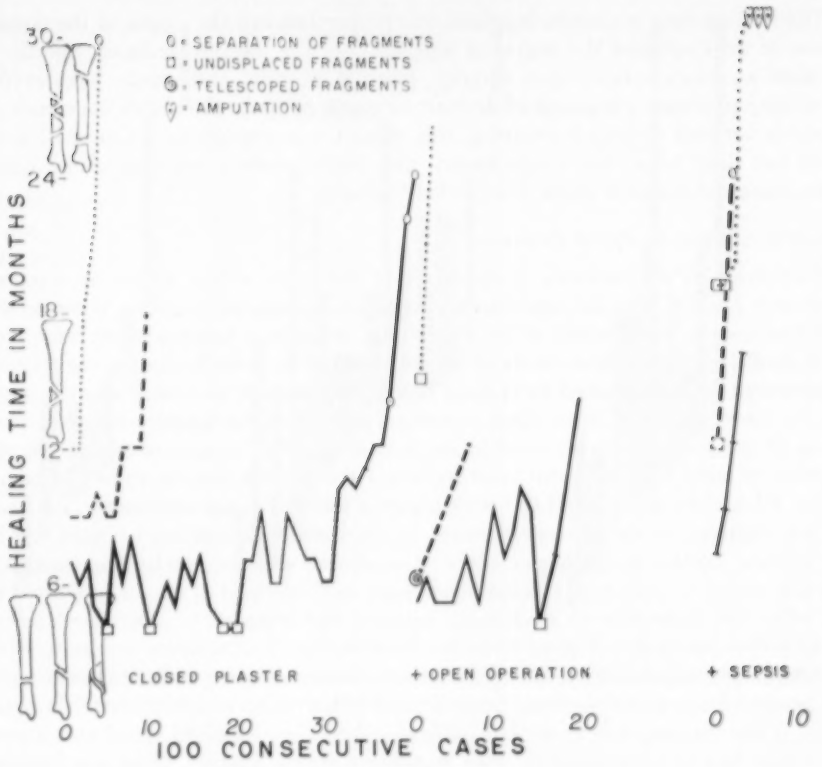

FIG. 1

Graphic summary of the end results in 100 control fractures of the tibia, showing the types of fracture and the healing time for each. Each point on the curve indicates one fracture. The solid lines show the healing times of sixty-five non-comminuted transverse, oblique, or spiral fractures. The dotted lines show healing times of twenty slightly comminuted fractures with a single wedge fragment. The broken lines show the healing times of fifteen highly comminuted and segmental fractures. The healing time was in general proportional to the amount of bone damage in the original injury. The healing time was greatly prolonged in comminuted fractures treated by open operations or complicated by sepsis.

routinely in the Department of Pathology. In addition to hematoxylin and eosin preparations, sections were cut from the same blocks for staining with toluidine blue and the techniques of (1) McManus-Hotchkiss and (2) Mallory-Heidenhain.

CONTROL CASES OF HEALED FRACTURES

The description and healing time of 100 consecutive fractures in patients treated and discharged without the diagnosis of ununited fracture or delayed union having appeared in the hospital records are summarized in Figure 1. These cannot be regarded as random or average samples of fractures of the tibia. Although union eventually occurred in all instances, with the exception of three fractures which resulted in early amputation of the leg, many of the patients were referred to the Veterans Hospital, as were those with non-union, because the fracture was extensive or complicated and required prolonged hospitalization. These patients were arbitrarily selected for controls because the fracture healed without a secondary surgical operation. The fractures in this group were used to match the type of bone injury, method of treatment, and complications with similar combinations of circumstances in ununited fractures. Several of these control fractures could be classified as having slow healing or delayed healing, but none could be regarded as having non-union because healing eventually resulted in a normal functioning leg.

The healing time in control fractures was proportional to the length of the damaged segment of the shaft and the degree of separation of the fracture surfaces. Specific factors, such as comminution, open surgery, internal fixation, and sepsis, were involved only as they produced a segment of devitalized tissue between the viable bone ends. The differences between control fractures in this respect was quantitative. Control fractures showed less dead bone, less displacement, and better contact between viable fracture surfaces than did matched cases of ununited fractures.

Transverse, Oblique, or Spiral Fractures

Non-comminuted fractures of the shaft of the tibia, either simple or compound, healed more rapidly than did comminuted fractures. Compound fractures, if converted to closed fractures by early suture of the wound, did not show a longer healing time. Extensive or poorly performed dissections of the fracture site in order to replace the fragments in anatomical position seemed to prolong healing to as much as twelve months in some cases. In closed fractures, when there was direct contact of the fracture surfaces, even as little as 50 per cent., union occurred in six to nine months. An area of separation of the fragments of more than 0.5 centimeter increased the healing time to twelve or eighteen months. When osteogenesis had to bridge a gap of more than one centimeter, the healing time was eighteen to twenty-four months. In fractures with contact between the bone ends, internal fixation had either no effect or no adverse effect on the healing time. It was never a stimulus to bone repair. Bone plates were well tolerated in non-comminuted fractures when the fragments were skillfully exposed and replaced in anatomical position, with all screws inserted well away from the fracture line. Transfixation screws were most effective in long oblique fractures and were least effective in short oblique fractures. Each screw produced necrosis of the bone tissue around it in a radius of approximately two millimeters. If the fracture was short and oblique rather than long and spiral and if two or three screws had to be inserted in order to achieve strong fixation, there was frequently enough necrosis of the bone around the metal to cause disintegration of the entire area of the fracture. When it was possible to place the metal screws widely apart, and when contact was maintained between the main fragments without stress long enough to apply a well fitted plaster cast, internal fixation was well tolerated and did not prolong the healing time of any type of non-comminuted fracture of the tibia.

Postoperative sepsis occurred in 4 per cent. of all types of non-comminuted closed and open fractures. The incidence of sepsis and delayed healing might have been lowered by a more careful selection of cases and a more perfect technique with internal fixation. The very good results in the majority of non-comminuted fractures could be used as evidence in favor of internal fixation, but the argument is weakened by comparison with the equally good results in matched fractures treated by closed methods. Although it is commonly said that the use of internal fixation requires special equipment and unusual skill, it was used in this series more commonly by inexperienced physicians in the community at large than it was by well informed and experienced surgeons.

Slightly Comminuted Fractures with Single Wedge Fragments

A single fragment of bone wedged between the main fracture surfaces was seen in 20 per cent. of the healed fractures. The healing time in these cases was generally nine to eighteen months. If the fragment had not been displaced, if it was large enough to have a broad periosteal covering with intact muscle attachments, or if there had been intentional telescoping of the fracture to produce good contact of the main bone ends, regardless of the eventual shortening of the leg, union often occurred in nine months or less. Internal fixation always prolonged healing if a large wedge fragment was dissected free of soft parts and was covered by metal. Sepsis, loss of skin covering, and other complications were generally more serious in the presence of avascular bone tissue. Healing was pro-

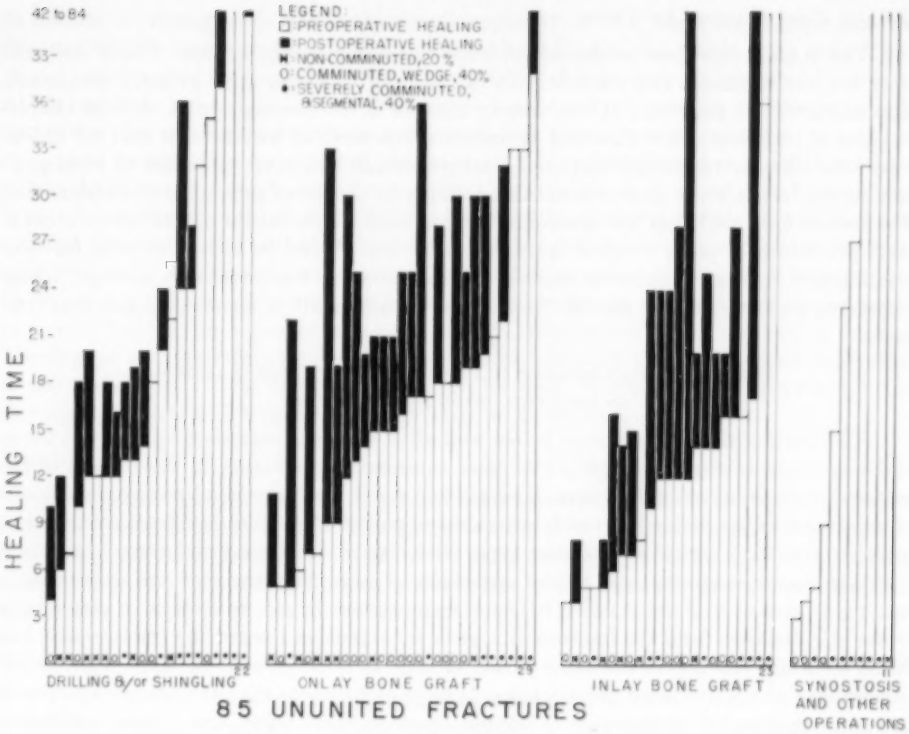

FIG. 2

Diagrammatic representation of the healing time before and after bone-grafting operations and other surgical procedures on eighty-five ununited fractures of the tibia. Each bar represents one fracture, and the symbols show the degrees of bone damage corresponding to the three types of fracture shown in Fig. 1. In the first group, three fractures were treated by drilling, fourteen by shingling, and five by a combination of drilling and shingling. In the second group, twenty fractures were treated by massive onlay bone grafts without excision of callus, and nine were treated by massive onlay grafts after excision of the callus and freshening of bone ends had been done. In the third group, twenty-three fractures were treated by inlay bone-graft operations. In the fourth group, three fractures were treated by tibiofibular synostosis operations, two by massive intramedullary grafts of the entire fibula and cancellous iliac-bone chips, one by apposing sliding massive grafts, and five by leg-shortening. The white section of the bar shows the healing time before the bone-graft operation; the black section of the bar shows the healing time after the bone graft had been placed. The end result was persistent non-union where no black section is shown in the fractures in the first three groups on the left.

longed if a free fragment of necrotic bone, however small, was interposed between the fracture surfaces.

Comminuted Fractures with Multiple Wedges and Segmental Fractures

The healing time of comminuted fractures which included more than one centimeter of the length and full circumference of the shaft was at least twelve months, and extended to as long as two and a half years in some cases. Segmental fractures, with the fracture lines greatly separated or with the fracture lines at each end of the diaphysis, were, of course, exceptions; these usually healed in the same time as single fractures. Open reduction and internal fixation of extensively comminuted fractures always prolonged healing and never encouraged it; open reduction and internal fixation produced disaster when complicated by sepsis. Serial roentgenograms showed that necrosis of bone was extensive and that osteogenesis was greatly depressed in fractures which had been subjected to open surgery as compared with those that had been treated by closed methods. Amputation of the leg was necessary in three of seven fractures treated by open methods.

Healing Time Required for Union

The control fractures in this series healed at a fairly regular rate. Union occurred after the use of almost every known modern form of closed or open primary treatment. Approximately 15 per cent., at one time or another in the healing period, showed characteristics of fractures often classified as ununited fractures or instances of delayed union; 5 per cent. closely resembled ununited fractures which had been subjected to bone-graft operations, but union in these was obtained simply by the use of prolonged immobilization. The results indicated that the minimum healing time which should elapse before a bone-graft procedure or other surgical operation is advised should be twelve months for non-comminuted fractures, eighteen months for comminuted fractures with a single wedge fragment, and twenty-four months for severely comminuted or displaced segmental fractures.

THE REPARATIVE PROCESS IN UNUNITED FRACTURES CLASSIFIED AS DELAYED UNION OR NON-UNION

The healing time of fractures before and after surgical treatment for delayed union and non-union is shown in eighty-five cases summarized in Figure 2. The length of the segment of the shaft which had been damaged and which had to be repaired and the amount of separation of the viable bone ends were always greater in an ununited fracture than in a matched control fracture of a similar type, with similar treatment and complications. A study of roentgenograms and biopsy specimens showed that the fracture underwent a healing process even if union failed to occur. Osteogenesis began, as always, in viable bone tissue at a distance from the fracture line, grew by extension toward the fracture site, but failed to bridge the gap in the same period of time as it did in control cases. Various circumstances which produced greater bone damage and defects than the body could repair in a prescribed period of time were (1) displacement, comminution, and missing substance, (2) surgical dissection of the fracture site, (3) exposed bone, (4) sepsis, and (5) metallic appliances.

Displacement, Comminution, and Missing Substance

Gaps produced by distraction or displacement filled at the rate of 0.5 centimeter per year. Fractures with defects of one centimeter or more in length required at least eighteen months to two years to heal. Missing substance, caused by extensive comminution and absorption of dead bone, was not uncommon and resulted in apparent widening rather than in filling of the fracture gap as seen in serial roentgenograms examined during the first six months of healing. Larger areas of missing substance were caused by extrusion of pieces of bone outside the periosteal tube. Sixty cases (78 per cent.) in this series of ununited fractures originally were comminuted fractures. Only nineteen (22 per cent.) were non-comminuted fractures, and nearly all of these showed unreduced displacement (an important technical error in treatment) or a serious wound infection. In more than a third (thirty-one) of the eighty-five ununited fractures, bone substance had been lost by the excision of callus, or by ostectomy, sequestrectomy, or saucerization operations done in order to control sepsis. If more than one centimeter of the length of the shaft had been excised in a leg with a healed fracture of the fibula, the reparative process was usually incapable of producing union in less than two years or longer.

Surgical Dissections of the Fracture Site

Débridement of compound fractures and open reduction of closed fractures often resulted in loss of vital soft-tissue attachments of the main fragments. This produced a situation in which more of the bone tissue of the bone ends was damaged than was ordinarily noted in undissected closed fractures. In comminuted fractures which had been opened surgically, the fragments behaved like free bone grafts. Such fragments did not act

as islands of osteogenesis; they were simply replaced by new bone which grew into the fracture site by extension from intact parts of the bone and the viable bone ends. Compound comminuted fractures, with large wedge-shaped fragments, or segmental fractures which had been treated by conservative methods that did not sacrifice soft-tissue attachments did show osteogenesis arising from small and large fragments of bone.

Serial roentgenograms were not always studied as carefully as they should have been before decisions were made concerning surgical treatment of patients with comminuted fractures (single or multiple wedge-shaped fragments, and segmental fractures). Serial roentgenograms showed that there *was* significant progress toward repair even in fractures with only scant deposits of external bony callus after one year of healing. It is important to emphasize that in every fracture in this series, united or ununited, all of the supernumerary fracture lines were consolidated into one fracture line within one year of healing. The final or ununited fracture line was nearly always the one with the greatest separation of the fragments. It was frequently also the location of implantation of some kind of metallic appliance which devitalized adjoining areas of bone.

Exposed Bone

Skin grafts (four split-thickness grafts and ten pedicle grafts) were required to cover exposed bone in fourteen ununited fractures. Osteogenesis was never observed on the surface of exposed bone tissue of the shaft of the tibia. At one stage or another of the healing process, there was gross wound sepsis in every one of the fractures with an exposed fracture line.

Sepsis

Tissue damage caused by sepsis was superimposed upon bone trauma in fifty (59 per cent.) of the eighty-five cases. Sepsis appeared either as a superficial wound infection or as actual osteomyelitis. In the former condition, there was no retardation of healing; possibly there was stimulation of bone repair. In the latter instance, there was often diffuse sclerosis of bone ends along a distance of four or five centimeters above and below the fracture line, with the typical picture of non-union seen in the roentgenograms.

Implantation of Metallic Appliances for Internal Fixation

The progress of healing in matched cases of ununited and united fractures showed that correctly applied internal fixation did not seriously prolong healing in non-comminuted fractures, but frequently led to disaster in comminuted fractures. In thirty-three cases, open surgery was followed by an extended period of healing or by a state of established non-union. Sepsis occurred in twenty-two of these fractures, causing extensive destruction of bone in twelve instances and amputation of the leg in four.

Thirteen spiral fractures were treated by transfixation screws; these were still ununited from nine months to two years after the operation. The cortical bone tissue between the screws was necrotic and had disintegrated. Although the original fracture line in each case was spiral, the pseudarthrosis developed in a transverse or oblique line. This transformation indicated that a certain amount of healing had to occur in order to produce the picture of non-union. Twenty-three fractures, treated with bone plates, showed excessive necrosis of bone ends and bone fragments, and showed similar changes in the configuration of the fracture line.

THE BONE GROWTH PHASES IN HEALING OF UNITED AND UNUNITED FRACTURES

The data on healing time and estimated bone damage in cases treated by open operation (Figs. 1 and 2) were combined; this data gave the bone-production curves in Figure 3. The points on the curve were plotted with the assumption that, if union occurred (after dissection of the fragments in open operation), the yield of new bone was equal to the

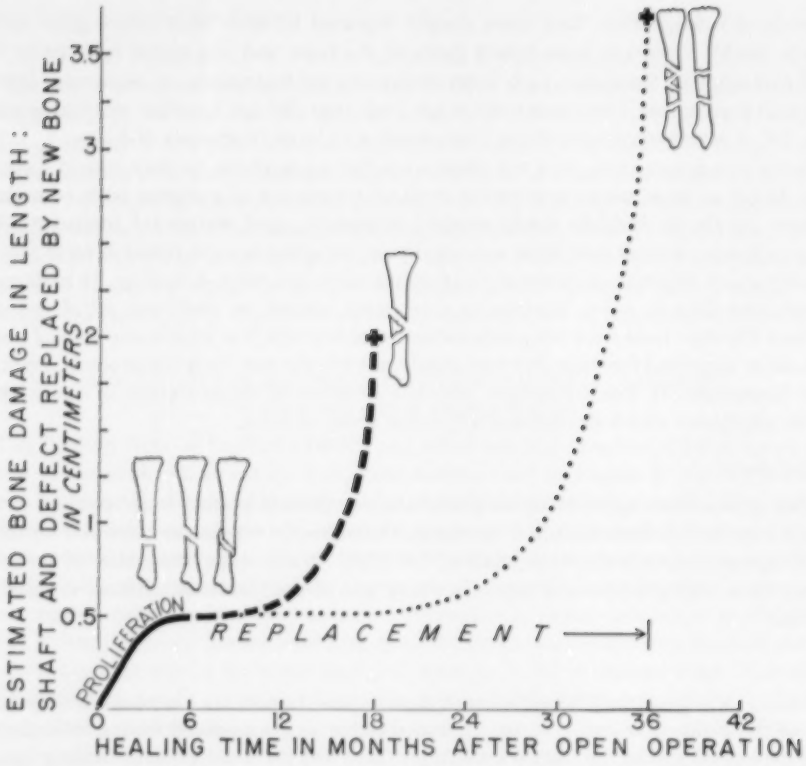

FIG. 3

Graphic illustration of healing time and yield of new bone in control fractures treated by open surgery and in ununited fractures treated by bone-grafting. Bone repair occurred in two phases. The proliferative activity of periosteum and endosteum of the bone ends occurred in the first phase during the first six months of healing. The replacement of cartilage, bone fragments, and bone grafts occurred in the second phase and continued for the duration of the period of healing.

amount of old bone which had been damaged. The healing of the fracture appeared to progress through two phases. The first phase of repair was characterized by proliferation of new bone from periosteum and endosteum of the main fragments; it may be termed the *proliferative phase*. Proliferation of external bony callus was apparent in serial roentgenograms between one and six months, after which the spindle of callus showed no appreciable increase in volume.

The second or *replacement phase*, during which union occurred, was marked by replacement of dead bone and fibrocartilaginous callus. The replacement phase was of minimum importance and hardly apparent in incomplete or undisplaced fractures which united in less than six months. It was of major importance and was greatly prolonged in fractures with displacement or large defects. The slope of the bone-growth curves, plotted from data gathered during the replacement phase, suggested that it was concerned with a much slower process than that in earlier stages. There was no change in the volume of the formation of periosteal bone or external bony callus during this phase. All of the new-bone formation apparently occurred inside the framework of fibrocartilaginous callus by intracartilaginous ossification or inside the substance of dead bone by replacement.

THE STRUCTURE AND ORGANIZATION OF THE CALLUS IN UNUNITED FRACTURES

Observations of the gross anatomy and histological structure were recorded from (1)

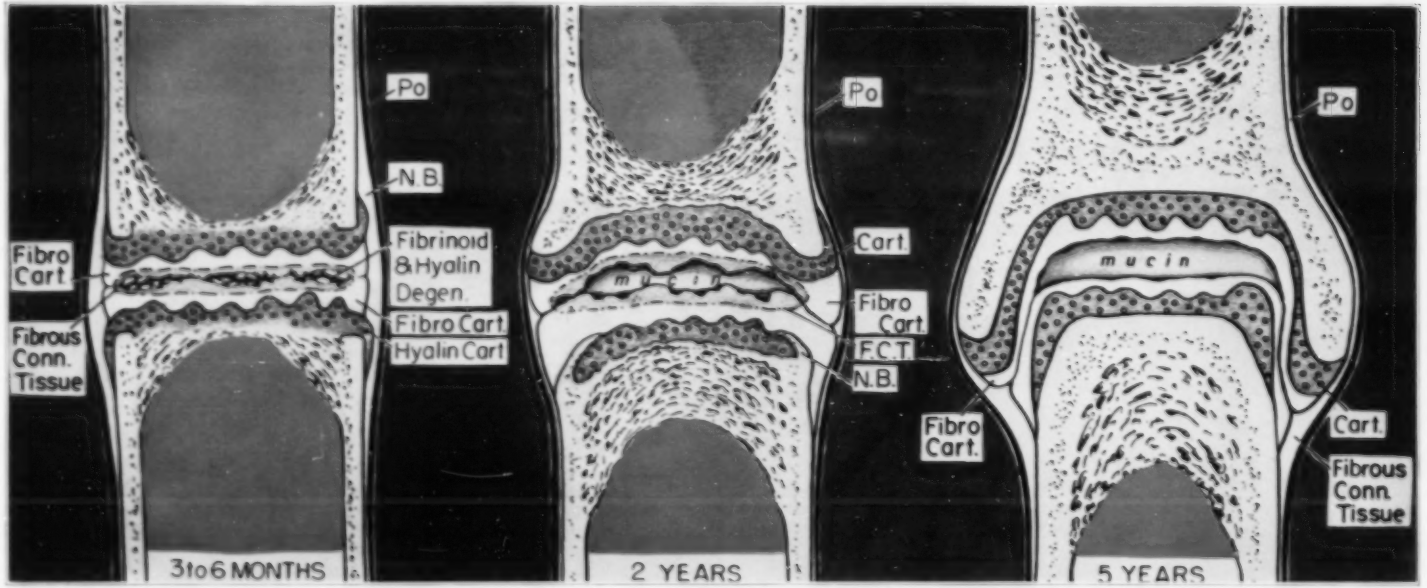

FIG. 4-A FIG. 4-B FIG. 4-C

Diagrammatic presentation of the three stages of the formation of a pseudarthrosis.

Fibrocart., fibrocartilage; *Po.*, periosteum; *N.B.*, new bone; *Cart.*, cartilage; *F.C.T.*, fibrous connective tissue; *Degen.*, degeneration.

Fig. 4-A: An amorphous area of fibrinoid and hyaline degeneration appears in the center of the callus during the first three to six months of healing.

Fig. 4-B: At any time before two years of healing have elapsed, a mechanical disturbance of the fracture will result in cleavage of the amorphous area and the formation of extracellular fluid containing mucin.

Fig. 4-C: Unrestricted motion at the fracture site, mechanical bruising, and inflammation of tissue is followed by continual fibrinoid degeneration of callus, overgrowth of bone all around the bone ends, and formation of false joint surfaces. Osteogenesis never actually ceases; it simply fails to bridge the fracture gap. The process of new-bone formation from one fragment seems to make an endless attempt to reach bone produced by the other fragment.

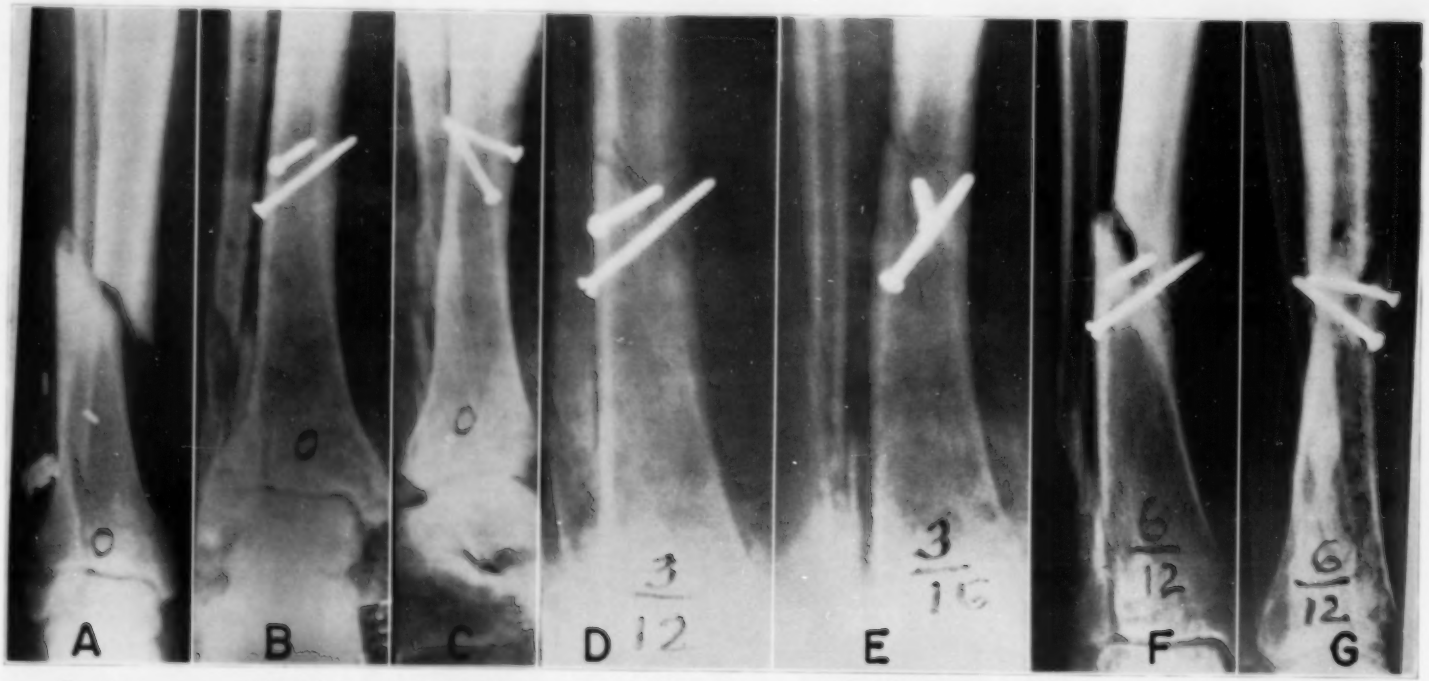

FIG. 5-A FIG. 5-B FIG. 5-C FIG. 5-D FIG. 5-E FIG. 5-F FIG. 5-G

Fig. 5-A: Roentgenogram showing a spiral fracture of the tibia and fibula in a man, fifty-five years old.

Fig. 5-B: Anteroposterior roentgenogram of the fracture of the tibia made after open reduction and internal fixation in perfect anatomical position.

Fig. 5-C: Lateral roentgenogram of the fracture of the tibia.

Fig. 5-D: Anteroposterior roentgenogram of the affected tibia in a plaster cast at three months.

Fig. 5-E: Lateral roentgenogram of the affected tibia in plaster at three months.

Fig. 5-F: Roentgenogram shows absorption of bone and separation of the fracture line after six months of continuous immobilization. One of the screws broke during the baths and non-weight-bearing exercises which had been prescribed for the knee and ankle joints too early in the healing period.

Fig. 5-G: A bone-graft operation had been performed and biopsy specimens were obtained for the sections shown in Figs. 5-H, 5-I and 5-J.

samples of the fibrocartilaginous callus obtained during bone-graft procedures or other surgical operations (fifty fractures), (2) whole specimens of the fracture site from amputated limbs (nine cases), and (3) an entire tibia which had been obtained at autopsy from one patient who had died of an unrelated disease seven years after the injury. The complete series revealed the structure of callus and bone ends at all stages from four months to seven and a half years of healing. Eleven fractures were exposed between four and six months of healing, thirty between six months and two years, and nineteen between two and seven and a half years. The findings in at least ten cases exposed before fifteen months of healing were essentially those of a normal healing fracture of the tibia. The findings characteristic of non-union are shown diagrammatically in chronological order in Figures 4-A, 4-B, and 4-C.

Four to Six Months of Healing

The structure of the callus seen in eleven slow-healing fractures of the tibia between four and six months after injury is shown in Figure 4-A. The fracture line was firmly enclosed in a spindle-shaped capsule of fibrous connective tissue and periosteum. The lateral and posterior aspects of the tibia on the periosteal surface showed thin deposits of cancellous new bone beginning at one or two centimeters above and below the fracture site. The bone ends were traumatized for a distance of one centimeter in non-comminuted displaced fractures, and as much as four centimeters in comminuted fractures which had been treated from the first with bone plates or multiple transfixation screws. The viable bone tissue behind the fracture surfaces always produced endosteal new bone. At the fracture line, the bone ends were covered with fibrocartilage and hyaline cartilage. These changes were the same as those observed in uncomplicated healing fractures [39]. The only tissue seen here and not seen in the control fractures was an amorphous material and inflammatory connective tissue in the middle of the fracture gap. The amorphous material consisted of a mixture of substances recognizable as fibrinoid, hyalin, and mucinous fluid. The surrounding area consisted of patches of necrotic connective tissue with pyknotic nuclei and chronic inflammatory connective-tissue cells.

In complicated fractures with large bone defects, the gap was first filled with a large fracture hematoma. The cartilage model, which formed later, was poorly constructed because of irregular, prolonged, and incomplete organization, and absorption of old fibrin. The hematoma was usually walled off and was partly liquefied inside a capsule of dense connective tissue. In some cases, the center of an old hematoma consisted of grossly purulent fluid. Sterile pus was found in the fracture site in closed fractures in which there was no conceivable source of infection, as well as in aseptically closed compound fractures and fractures reduced by open operation. The quantity of amorphous material and necrotic tissue was greatest in cases with wound infections and chronic sepsis in the fracture site. Inflammation, sterile or septic, generally accompanied the formation of the amorphous substances in the callus of ununited fractures.

Fibrinoid: The principal constituent of the amorphous center of the callus was fibrinoid, a material which is not a single chemical substance, but a mixture of substances well known since 1880 when Neuman described the lesions of various systemic and traumatic inflammatory conditions. The presence of fibrinoid in the callus of ununited fractures was identified in this study with the aid of histochemical techniques recently evaluated by Bennett [5] in a review of histopathology of collagen diseases. Fibrinoid as seen in callus was acellular, homogeneous or refractile, fibrin-like (but it was not fibrin), acidophilic or eosinophilic, metachromatic-staining with toluidine blue, pink-staining with the McManus-Hotchkiss procedure, and staining a mixture of orange, brown, yellow, *and blue* with phosphotungstic acid and hematoxylin. Morphologically, fibrinoid appeared as a mass of material consisting of collagen and ground substance in all stages of degradation. Fibrinoid has been produced experimentally by mechanical trauma which bruised tissue and caused

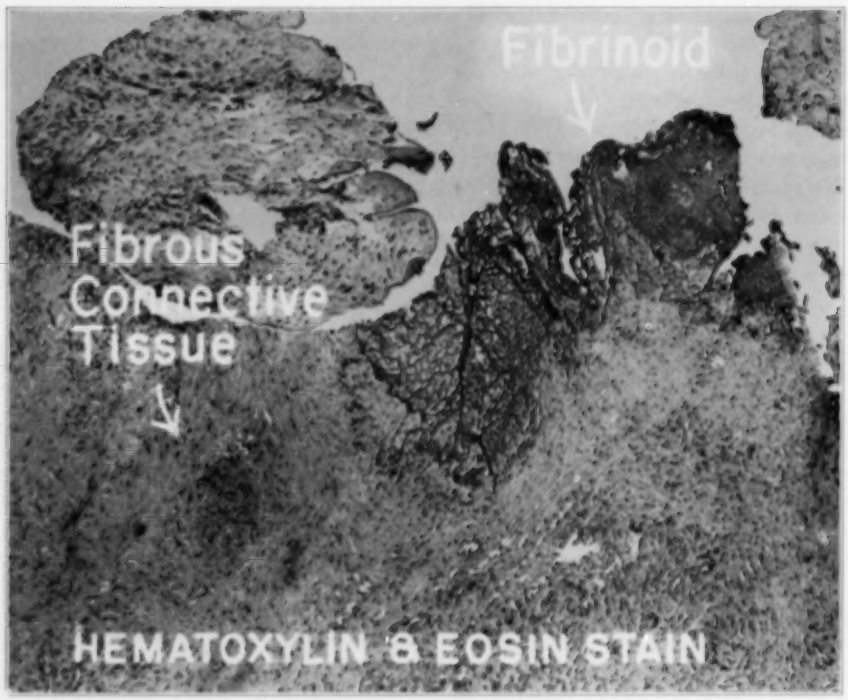

FIG. 5-H

Photomicrograph of the tissue removed from the center of the callus of the oblique fracture of the tibia shown in Figs. 5-A through 5-G, seven and a half months after internal fixation with two transfixation screws, showing fibrous connective tissue, chronic inflammatory tissue, amorphous material, and fibrinoid, with no evidence of new-bone formation anywhere inside the fracture gap. (Hematoxylin and eosin stain.)

extravasation of plasma into normal connective tissue [46]. Precipitation of acid mucopolysaccharides from the ground substance by substances derived from necrosis of tissue is generally believed to be the mechanism of formation of fibrinoid. The reactions with toluidine blue or with periodic acid and leukofuchsin reagents varied in intensity with the proportion of acid mucopolysaccharides to other substances in the fibrinoid. The process began as a relatively light-staining fibrinoid change and later became more deep-staining fibrinoid degeneration. It terminated in complete disintegration and liquefaction of the material. All of these changes resembled in every respect the pathological process in chronic adventitious bursitis.

Pseudarthrosis fluid and mucin: Associated with fibrinoid degeneration of the connective tissue in the center of the callus, there was local accumulation of a mucinous fluid. In fractures in which there was free motion between the bone ends, there was also spreading apart of the inflammatory connective tissue and formation of a pool of extracellular

Fig. 5-I: Photomicrograph (× 200) of another section of the same area, stained in Mallory's phosphotungstic acid and azan. The fibrous connective tissue stained red. The fibrinoid stained irregularly in brown, orange, and yellow, and contained areas of coagulated blue and purple-staining material.

Fig. 5-J: Photomicrograph (× 300) of another section of the same area stained by the McManus-Hotchkiss technique. Fibrinoid appears on the left side of the picture, pale pink to purple-red in color, and shows the positive reaction for glycoproteins or acid mucopolysaccharide substances. The reaction depends upon oxidation of hydroxyl or hydroxylamino groups to aldehyde groups by periodic acid (H_5IO_6) and by addition of leukofuchsin to form a polysubstituted dye compound which is pale pink to purple in color. This differs from most tinctorial techniques in that it has the distinction of being a true chemical reaction with the ground substances of connective tissue.

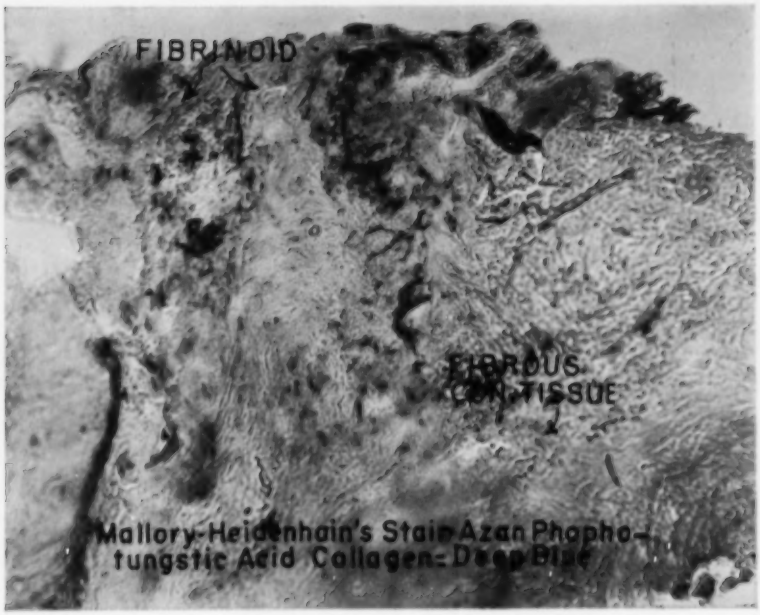
FIBRINOID
FIBROUS CON. TISSUE
Mallory-Heidenhain's Stain Azan Phospho-tungstic Acid Collagen: Deep Blue

FIG. 5-I

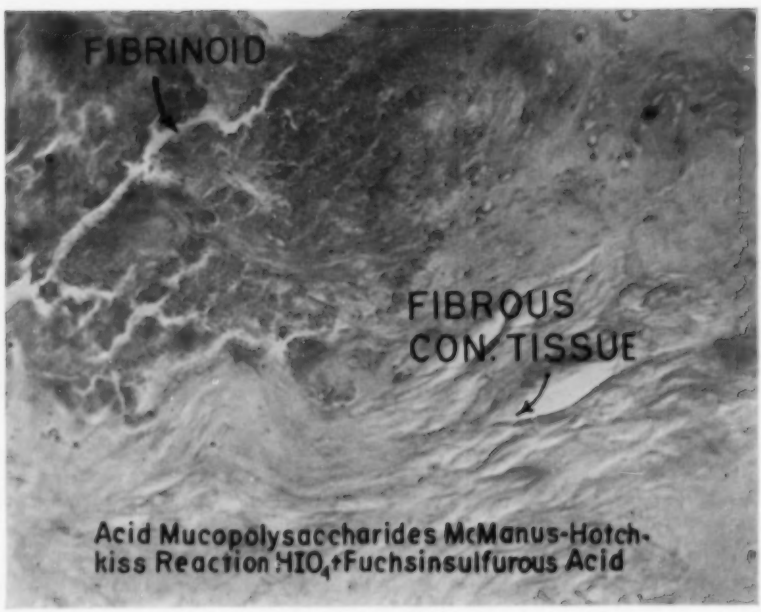
FIBRINOID
FIBROUS CON. TISSUE
Acid Mucopolysaccharides McManus-Hotchkiss Reaction HIO_4+Fuchsinsulfurous Acid

FIG. 5-J

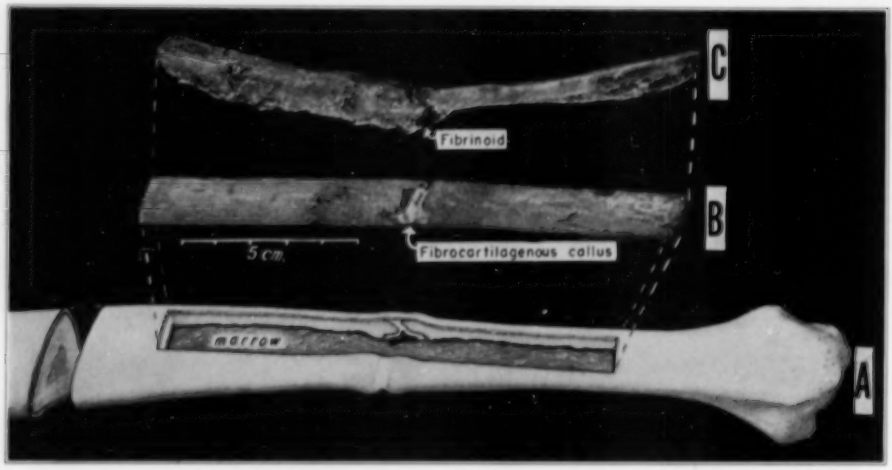

FIG. 6-A

A: Artist's sketch of an ununited fracture of the shaft of the tibia exposed at open operation for an inlay bone graft from the opposite tibia, one year after injury.

B: Top-view photograph of a specimen of bone ends and fibrocartilaginous callus, excised with a twin-blade power saw. (Contributed by Col. Leonard T. Petersen, United States Army Medical Corps, May 7, 1941.)

C: Side-view photograph of the same specimen, illustrating endosteal new bone inside the proximal bone end, the fracture gap, and the location of fibrinoid shown in Figs. 6-D and 6-E.

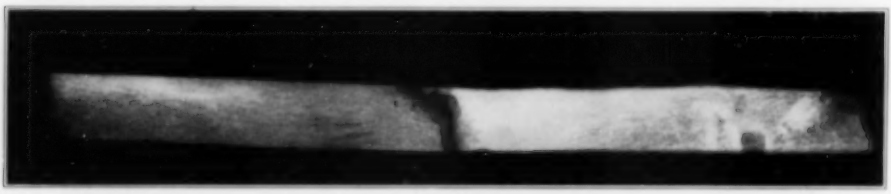

FIG. 6-B

Roentgenogram of the top view of the same specimen, showing the fracture gap.

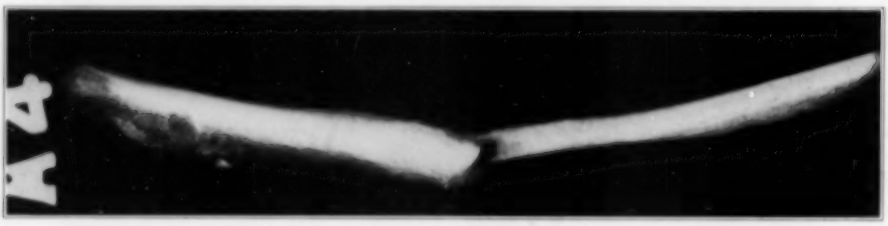

FIG. 6-C

Roentgenogram of the side view of same specimen, showing the thickness of the cortical bone ends.

viscous fluid, similar to that seen in inflamed bursae. The mucinous substance in an early pseudarthrosis stained metachromatically with toluidine blue and resembled the protein-polysaccharide complex found in bursal fluid. Friction and motion between the bone ends caused inflammation and trauma which produce increased capillary permeability and extravasation of fluid into the amorphous material. It is possible that fibrinoid imbibes

Fig. 6-D: Photomicrograph (× 100) of fibrocartilaginous callus with an area of fibrinoid degeneration in the callus between the bone ends. The clear area was filled with mucinous fluid. The corrugations in fibrinoid are artefacts in sectioning this extremely friable material. (Hematoxylin and eosin stain.)

FIG. 6-D

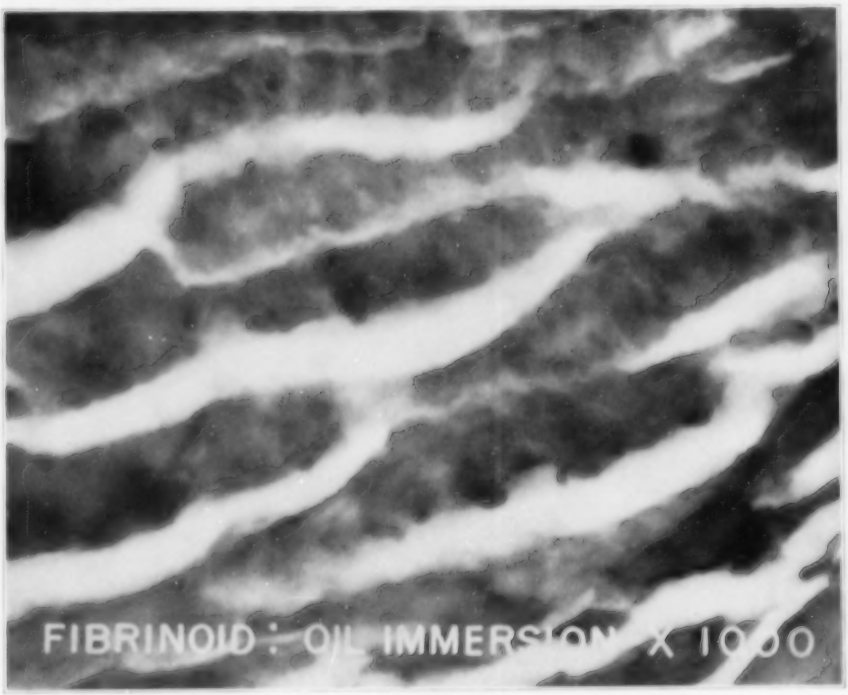

FIG. 6-E

Fibrinoid from the same specimen shown in Fig. 6-D in high-power magnification (oil immersion lens, × 1,000), showing the amorphous nature of the material.

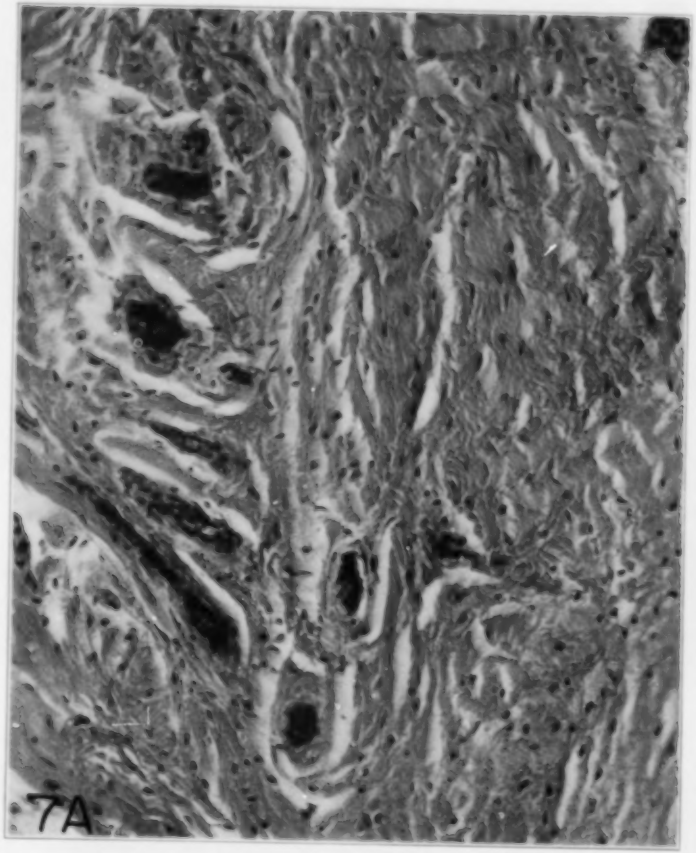

FIG. 7-A

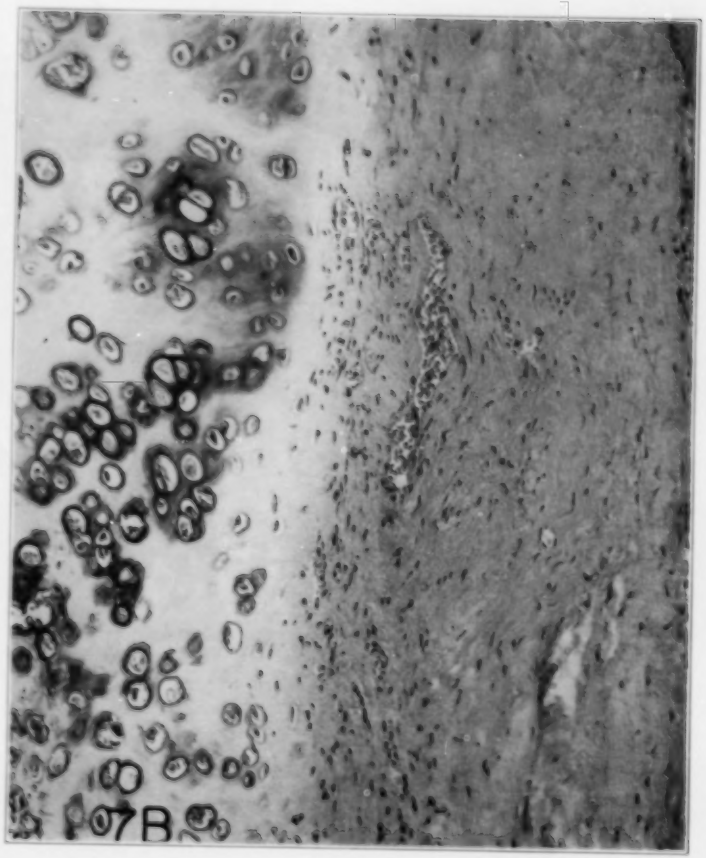

FIG. 7-B

Figs. 7-A through 7-D: Photomicrographs illustrating the various tissues found in the callus of the ununited fracture of the tibia shown in Figs. 7-E, 7-F, and 7-G. (Hematoxylin and eosin stain.)

Fig. 7-A: Photomicrograph of the fibrous capsule which enclosed the fracture site, showing perivascular round-cell infiltration and chronic inflammatory cells.

Fig. 7-B: Photomicrograph showing fibrous capsule, fibrocartilage, and hyaline cartilage.

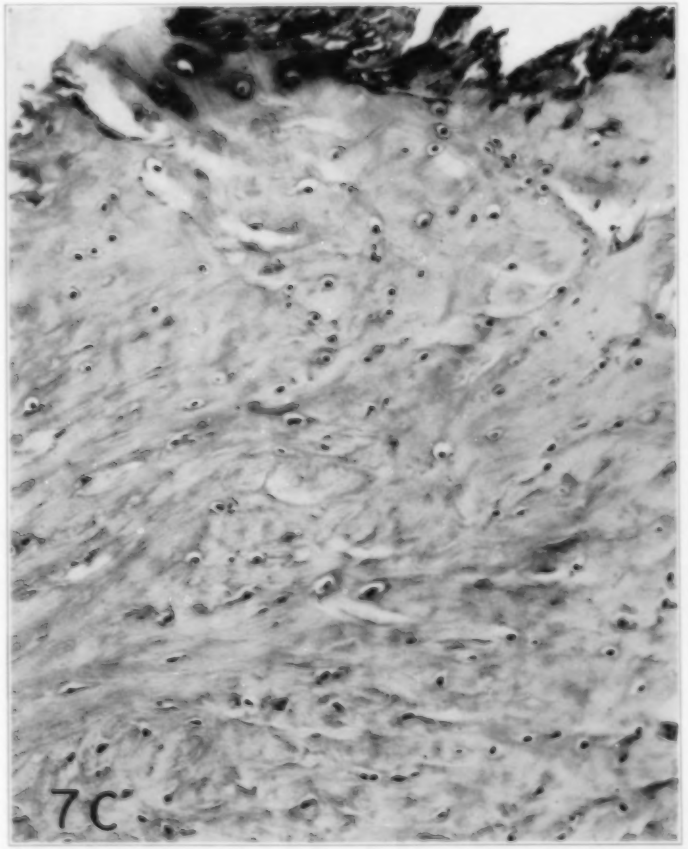

FIG. 7-C

FIG. 7-D

Fig. 7-C: Photomicrograph showing structure of the fibrocartilage and hyaline cartilage which covered the bone ends.

Fig. 7-D: Photomicrograph showing fibrinoid and hyaline degeneration in the center of the callus. The clear spaces at the right side of the picture originally contained mucinous fluid.

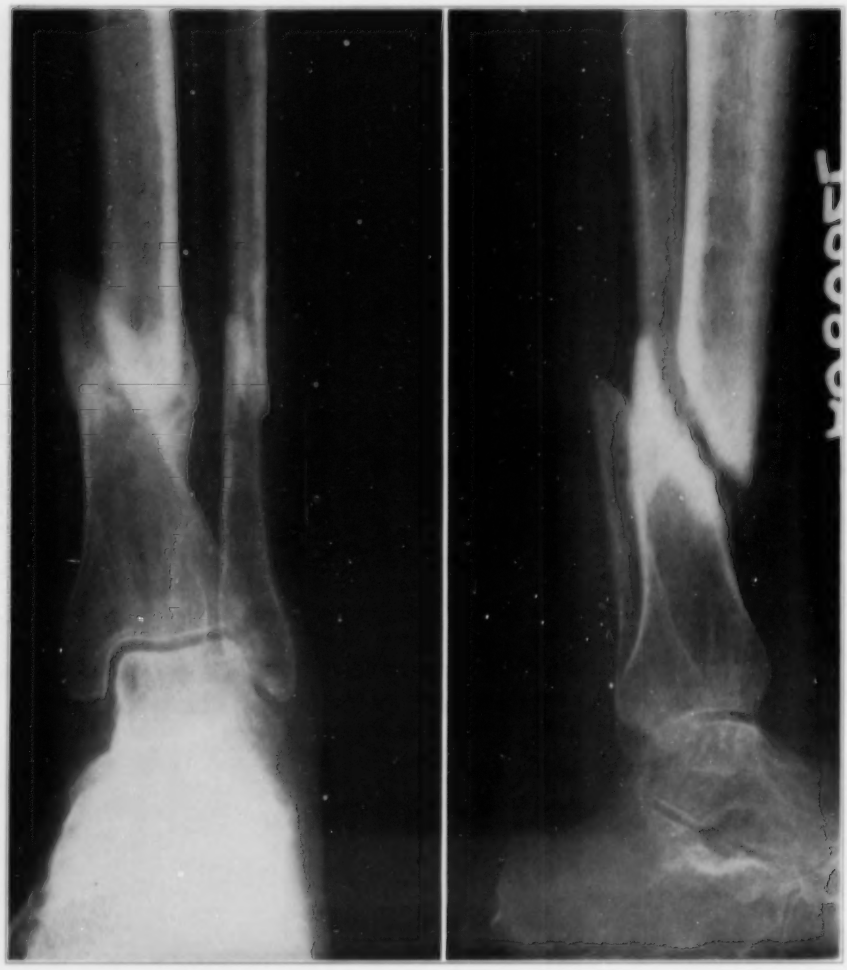

FIG. 7-E FIG. 7-F

Fig. 7-E: Anteroposterior roentgenogram of an ununited fracture of the tibia at two years and nine months of healing.

Fig. 7-F: Lateral roentgenogram showing the pseudarthrosis.

water and leads to the formation of the pseudarthrosis fluid. Very little is known, however, about the composition of these substances and the exact chemical reactions which produce the false joint fluid.

Hyalin: Patches of hyalin were also found in varying amounts in the callus of ununited fractures. This material was acidophilic and eosinophilic, homogeneous, and refractile, and did not have the granular or fibrillar consistency of fibrinoid. It further differed from fibrinoid in that it did not stain metachromatically with toluidine blue and was negative to the McManus-Hotchkiss procedure. Hyalin stained only yellow, orange, or brown, and had no blue-staining elements with phosphotungstic acid and hematoxylin. The quantity of hyalin increased with the age of the callus. Both fibrinoid and hyalin have been seen in very small amounts in normal healing fractures, chiefly in procallus; they are never seen in the later stages of healing.

Regression of scar: Uncomplicated healing fractures showed a large mass of granula-

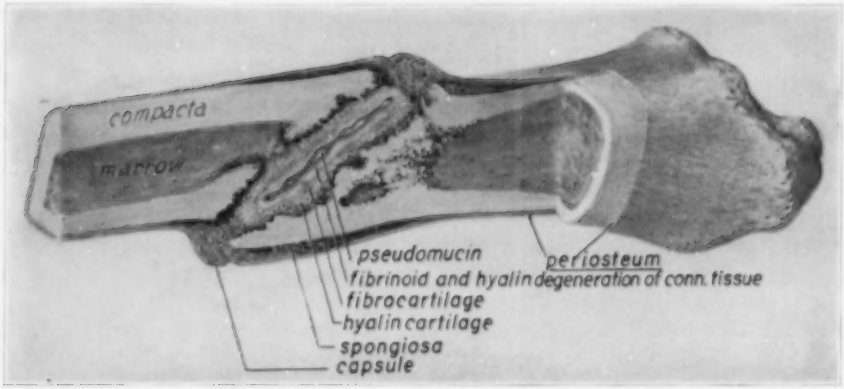

FIG. 7-G

Artist's conception of the gross and microscopic anatomy of the callus of the ununited fracture shown in Figs. 7-E and 7-F, reconstructed from the small samples of tissue obtained from all parts of the fracture site exposed for a bone-graft operation. The histological structure of the various parts of the fracture callus in this case is shown in Figs. 7-A through 7-D.

tion tissue and young fibrous connective tissue which formed with the organization of the fracture hematoma. Part of the young fibrous connective tissue developed into dense scar tissue, and was arranged in bands and layers between nodules of fibrocartilaginous callus. The entire callus was eventually absorbed and was replaced by new bone by means of the process of regression of scar. This has been described in detail by cytologists, but it is known only as an elusive change in which connective-tissue cells simply disappear. A striking feature of the callus of ununited fractures, particularly when complicated by chronic sepsis, was the failure of the process of regression of scar. Scar formation was obviously stimulated by inflammation, either traumatic or septic. New-bone formation did not occur inside old infected scar tissue.

Six Months to Two Years

Figure 4-B is a composite diagram of the structure of the callus observed at intervals between six months and two years of healing in fifty ununited fractures. A fibrous capsule was formed in continuity with periosteum which served to envelop the bone ends and the fibrocartilaginous callus. Beneath the thickened periosteum or capsule, at some distance above and below the fracture line, there were nodular deposits of cancellous and compact new bone. Similar deposits were formed from endosteum across the marrow cavity. There was nearly always external bony callus on the posterior aspect of the proximal fragment. At all stages and in every case, each bone end was capped with fibrocartilage and hyaline cartilage. If the bone ends were freely movable, the callus showed areas of chronic inflammatory connective-tissue cells, patches of fibrinoid, hyalin, and a space filled with highly mucinous fluid. In twenty-four cases, the fractures of the tibia and the fibula were ununited. Non-union of both bones permitted a wide excursion of the bone ends which may have encouraged continuous production of fibrinoid. In such cases, after eighteen months, walking casts and braces often permitted enough hinging motion to produce dense compact bone along the fracture surfaces, and probably contributed to the development of a pseudarthrosis. In instances in which there was missing substance of the tibia, the fibula sometimes united early and served to hold the bone ends apart until they healed like two opposing and separate amputation stumps. Such cases showed amorphous material, less mucinous fluid, and no molded false joint surfaces (Figs. 6-A through 7-G).

Two to Five Years

Nineteen fractures showed the formation of a mature pseudarthrosis. The proximal

bone end had become expanded, had become shaped like a metaphysis, and a saucerized or concave surface had developed. The distal bone end had usually become rounded or convex. In one case, the proximal bone end had almost completely enclosed the distal end in the manner of a ball-and-socket joint. The concave component had hyaline cartilage all around the rim, and there was fibrous tissue with spots of bare bone in the center of the hollow. The convex end was smoothly covered with fibrocartilage on the dome, with a ring of hyaline cartilage around the rim.

Microscopically, both fracture ends showed an articular cortex composed of very dense cancellous bone and compact bone. Fibrocartilage and bone were woven together at the pseudarticular surface by collagenous fibers crossing from cartilage to bone matrix. There was no intermediate (basement) membrane such as that found beneath the articular cartilage of normal joints. The pseudarticular surface was a heterogeneous mixture of fibrocartilage, fibrous connective tissue, and laminated amorphous material, including fibrinoid. There was never uniform false synovial membrane. The fluid which filled the false joint cavity in the manner of normal synovial fluid was more viscous than bursal fluid.

One of the most remarkable features of the shaping of the bone ends of a pseudarthrosis was the continuous increase in the quantity of new bone laid down from the rim of the proximal bone end. Osteogenesis progressed steadily all around the fracture gap but never across it. The new-bone formation continued along the line of contact with the fibrocartilaginous cover of the proximal fragment. A fracture failed to unite, but it appeared that there was never an end to the process and effort of healing. It was obvious that the quantity of the new bone produced was more than enough to unite the fracture if it had been deposited in the proper place; but union did not occur because osteogenesis was not drawn into the fracture gap (Figs. 8-A through 8-C).

THE EFFECT OF VARIOUS SURGICAL OPERATIONS UPON UNUNITED FRACTURES

The results of ten different types of surgical procedures were condensed into four groups and are summarized in Figure 2. Fresh autogenous bone was used in all fractures of the tibia treated with bone grafts at Wadsworth General Hospital from 1948 to 1953. We have no objection to the use of homogenous bone grafts in ununited fractures of such other bones as the femur, but we have been reluctant to use anything except fresh autogenous bone in such a relatively unfavorable host bed as the tibia.

Biopsy examinations of callus and examination of tissue from amputations following bone-graft operations on twelve fractures suggested that the function of the transplanted bone tissue and its effect upon fracture healing was to promote osteogenesis from the fracture ends. The donor tissue itself did not appear to proliferate, to change in volume, or to enter into the fracture healing any more than a catalyst or an enzyme enters into a chemical reaction. All of the new bone laid down between the fracture ends developed from the host bed, grew through fibrocartilaginous callus, across the fracture site, and established union, by the same pattern as it did in uncomplicated bone repair, before the graft had been fully incorporated or replaced. The traditional views of this series of events have been to regard the bone graft as a source of osteogenetic cells, a passive scaffold for osteogenesis, an ordinary form of absorbable internal fixation, or as a stimulus to new-bone formation. Any one, or any combination, of these ideas may be defended as the correct interpretation of the phenomenon of bone-grafting. The fact is that the osteogenetic tissues of the host display a specific affinity for the substance of the bone graft, and can grow into it whether it is autogenous, homogenous, or even heterogenous. An analysis of the various types of operations for the ununited fractures of the tibia in this series of cases suggested that all surgical procedures introduced a new injury, a new proliferative response, and a booster mechanism for osteogenesis. The bone graft was incorporated in the host bed after union had occurred in various ways, depending upon the technique of the operation. The time required to produce union, whether or not a bone graft had been implanted,

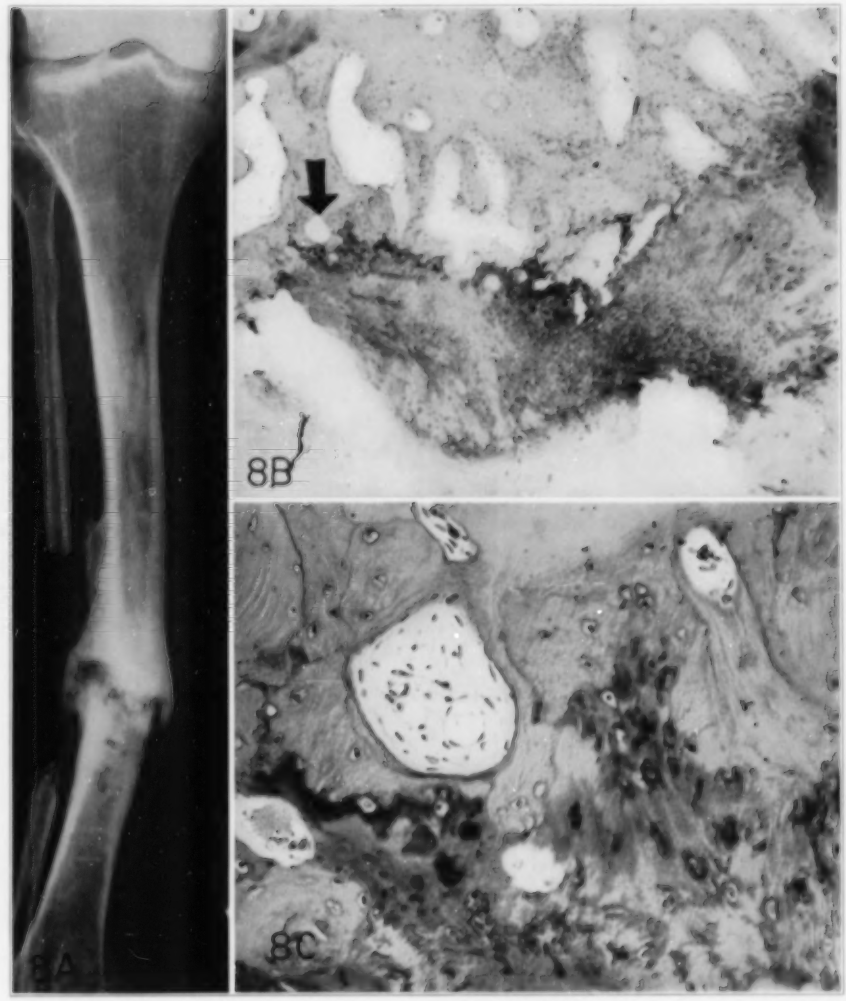

FIG. 8-A FIG. 8-C

Fig. 8-A: Anteroposterior roentgenogram of a five-year ununited fracture of the tibia (two years after failure and extrusion of bone grafts of iliac cancellous chips and a massive graft from the ipsilateral fibula). The patient was fitted with a caliper brace, and a mature pseudarthrosis developed with a structure such as that shown diagrammatically in Fig. 4-C.

Fig. 8-B: Photomicrograph showing the structure of a functioning pseudarthrosis. Dense hyalinized fibrocartilage forms the surface of the false joint; the compact bone forms a pseudarticular cortex. The area indicated by the arrow is shown in Fig. 8-C.

Fig. 8-C: Photomicrograph showing the interdigitation of the compact bone fibers with hyaline cartilage and old fibrocartilage which forms the weight-bearing surface of the false joint.

was highly variable, and depended mainly upon the preoperative condition of the fracture.

Drilling of the bone ends: The oldest surgical method of stimulating osteogenesis in ununited fractures was introduced in the era of subcutaneous surgery and is known as drilling of the bone ends[8]. The operation was used in this series of cases only in its modern form as an open operation. Drilling was regarded as indicated in cases in which the roentgenograms showed sclerosis or sealing of the bone ends. It was found to be of no particular value in fractures with increased bone density due to latent sepsis. Drilling of the bone ends without bone-grafting was done in only three cases; this was not a fair test of the procedure. In one patient it was performed after nearly three years, and in another after

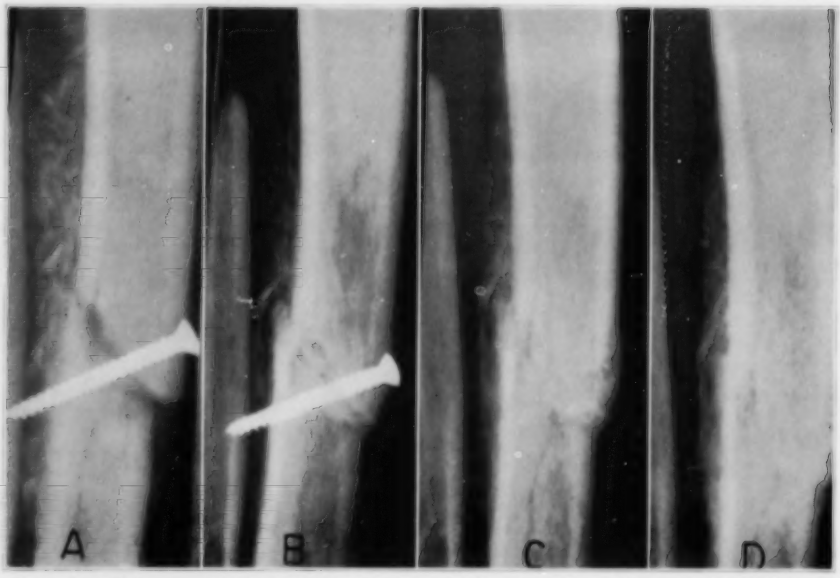

FIG. 9-A FIG. 9-B FIG. 9-C FIG. 9-D

Fig. 9-A: Roentgenogram illustrating "shingling" of an ununited fracture of the tibia; this was done by lifting chip grafts from the lateral cortex, without excision of fibrocartilaginous callus, thirteen months after injury. Originally the fracture had been treated by open reduction and screw fixation and came apart after one year of immobilization in a toe-to-groin cast.

Fig. 9-B: Two months after the shingling operation. Note the beginning of consolidation of the chip grafts, but the fracture has already united.

Fig. 9-C: Solid union of the fracture seven months after shingling of the fracture, and twenty months after injury. The head of the screw could be felt subcutaneously and was removed at this time through a stab wound on the anteromedial aspect of the leg. The chip grafts are seen becoming consolidated within a plate of new bone across the lateral aspect of the already united fracture.

Fig. 9-D: Ten months after shingling and twenty-three months after original injury, complete consolidation of both fracture site and chip grafts.

three years and nine months; failure resulted in both. In a third patient, the operation was done at seven months after the fracture, but was ill advised because the fracture site contained more than three centimeters of old infected and inactive sclerotic bone which could not be stimulated by simple drilling of the bone ends.

Shingling: The operation was used as a single procedure to produce an osteogenetic reaction in fourteen cases,—in five at less than one year, in five at less than two years, and in four at less than four years after injury (Figs. 9-A through 9-D). In this operation, the pseudarthrosis was not excised, except to remove a thin slice of the fibrocartilaginous callus and a sample of the bone ends for biopsy examination. After considering Phemister's conclusive demonstration that freshening of the bone ends is unnecessary for bone-grafting in cases of delayed union[35] and the common knowledge that some of these cases of delayed union might have united with no other treatment than six to nine months of further immobilization in plaster, it seemed natural for us to suspect that the bone graft *per se* was only a part of the process which produced union of the fracture. An examination of serial roentgenograms of the bone changes following a shingling operation indicated that this assumption was correct. The surgical operation produced the chip grafts, introduced a new injury, and stimulated a new osteogenetic reaction from the bone ends. Before or during the process of consolidation of cortical bone shavings, new-bone formation appeared on the unexposed sides of the shaft and between the bone ends. The fracture promptly united in eight cases treated before eighteen months of healing, and failed in three cases of non-union treated less than two years after the original injury. In three

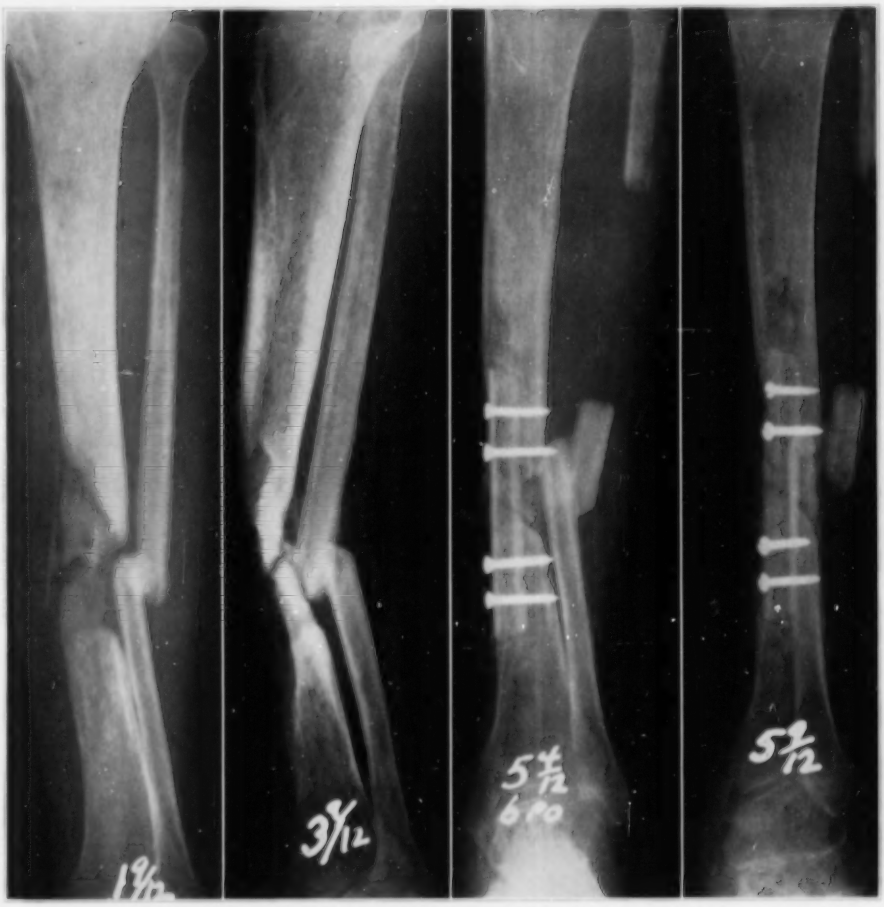

FIG. 10-A FIG. 10-B FIG. 10-C FIG. 10-D

Fig. 10-A: Anteroposterior roentgenogram of an ununited fracture of the tibia with loss of substance and active sepsis twenty-one months after primary treatment of a compound fracture by bone-plating.

Fig. 10-B: Lateral roentgenogram three years and nine months after injury and after three sequestrectomy operations in an attempt to control sepsis.

Fig. 10-C: Anteroposterior roentgenogram showing massive inlay bone graft from the ipsilateral fibula, six months after operation and five years and four months after injury.

Fig. 10-D: Anteroposterior roentgenogram eleven months after operation (five years and nine months after injury), showing recurrence of infection and an area of absorption of bone tissue in the upper bone end.

instances in which the shingling procedure was performed on fractures with established non-union more than two years after the injury, healing failed to occur in two instances and produced insufficient bridging of the bone in one. The indications and the limitations of the shingling operation appear to be as follows: (1) The operation should not be used in patients in whom the fracture gap is more than 0.5 centimeter; (2) shingling without excision of the fracture site and osteotomy of the fibula (to produce close contact of the bone ends of the tibia) was likely to fail in fractures ununited longer than eighteen months; and (3) shingling should not be done on fresh fractures prior to the formation of a solid fibrocartilaginous callus in the fracture gap.

Drilling and shingling: Combined drilling of sclerotic bone ends and shingling of the lateral cortex of the tibia was performed upon five cases and succeeded in producing union

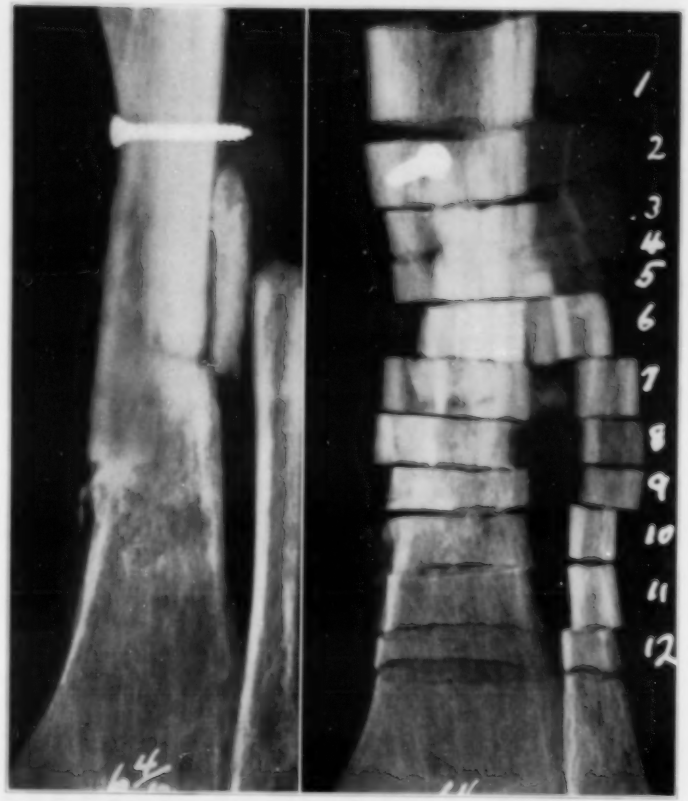

FIG. 10-E

FIG. 10-F

Fig. 10-E: Roentgenogram of amputation specimen of the fractured tibia shown in Figs. 10-A through 10-D, one year after operation (six years and four months after injury). The three lower screws have been removed, while the upper screw has been retained to serve as a marker.

Fig. 10-F: Anteroposterior roentgenogram of same specimen after it had been

(*Continued on page 955*)

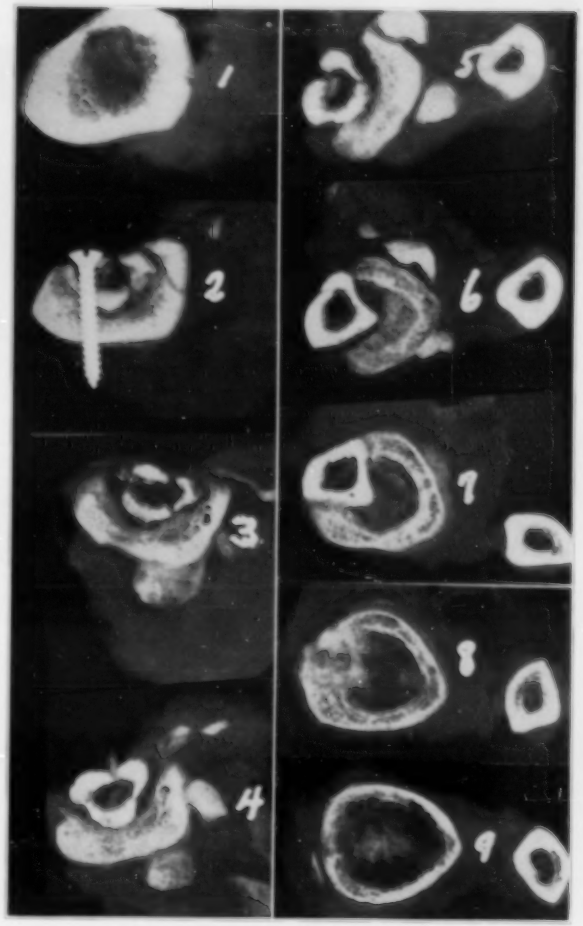

FIG. 10-G

(Fig. 10-F, *continued from page 954*) prepared in cross sections which were numbered from one to twelve to identify each level of the fractured tibia.

Fig. 10-G: Roentgenograms of the upper nine slices in cross-section, showing absorption of the graft in the area of sepsis seen in the sections numbered 2 and 3. Retention of the graft and proliferation of endosteal bone from the host bed is seen around the non-septic distal bone end in sections numbered 7 and 8.

Fig. 10-H: Photomicrograph (× 3) from section numbered 3, showing necrosis and fragmentation of the fibular bone graft inside the medullary cavity of the tibia.

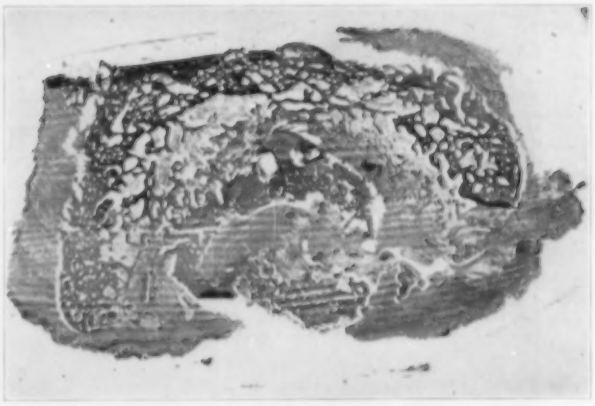

FIG. 10-H

in six to nine months in all instances except one. A study of serial roentgenograms showed that the fracture site reacted to combined drilling and shingling in the same way that it reacted to either procedure alone, and there was no evidence that the two procedures supplemented each other.

Onlay bone grafts: Twenty fractures were treated by the application of a simple onlay bone graft without altering the position of the fracture or excision of the pseudarthrosis; nine were treated by radical excision of the callus and freshening of the bone ends at

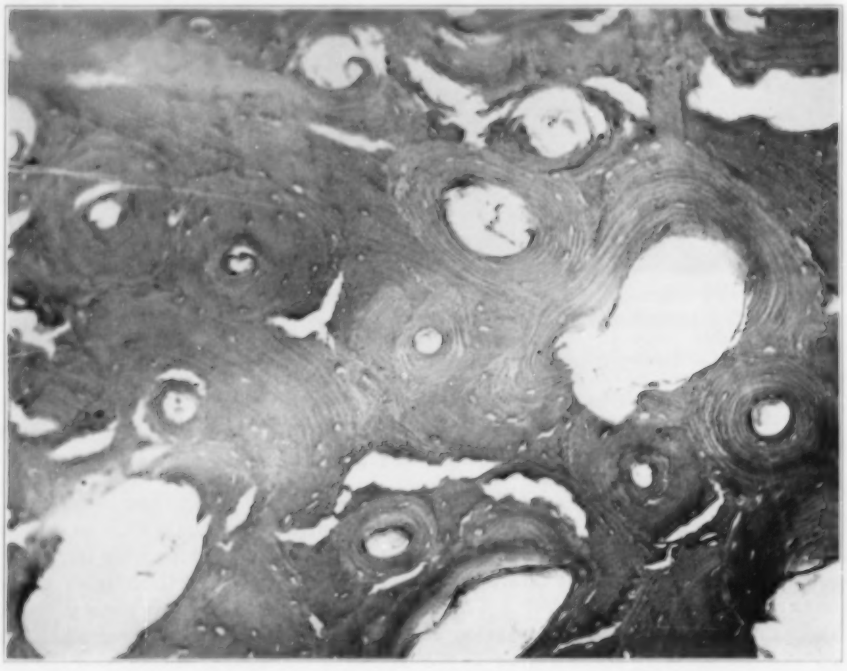

FIG. 10-I

Photomicrograph of cross section of sclerotic proximal bone end (which proved to be an area of latent sepsis). Note the empty lacunae and complete necrosis of old compact bone. The enlarged Haversian canals contained purulent exudate and acute inflammatory connective-tissue cells which were lost in sectioning the hard bone. The split areas are artefacts.

FIG. 11-A FIG. 11-B FIG. 11-C FIG. 11-D

Fig. 11-A: Anteroposterior roentgenogram, showing ununited fracture of the tibia, with a large bone defect, three years after injury and intractable sepsis.

Fig. 11-B: Lateral roentgenogram showing increased density, necrosis, and fragmentation of bone ends.

Fig. 11-C: Anteroposterior roentgenogram made three months after compression of the bone ends, removal of transfixation pins, and continuous purulent drainage from the fracture site.

Fig. 11-D: The fracture was ununited fifteen months after implantation of bone grafts, and eight years and three months after injury.

the time that the graft was implanted. The graft was obtained either from the crest of the ilium or the adjacent fibula. A freshly bleeding bone surface was made with an osteotome in order to prepare a flat surface in the host bed. No extra bone chips were implanted in fifteen cases. In three cases the lateral aspect of the tibia was also thoroughly shingled, and in two the bone ends were drilled. The condition of the skin and soft parts determined the approach to the leg and the position of the graft. Usually the anteromedial side of the leg was considerably scarred from an old wound or a healed infection, and the lateral side offered a healthy area for a new incision and a clean host bed. In three fractures there was a history of a recent wound infection, dense scar, and cyanotic oedematous skin on the anterolateral aspect of the leg. In these, the incision was made on the posteromedial aspect. The graft was introduced through the posterior compartment of the leg and was

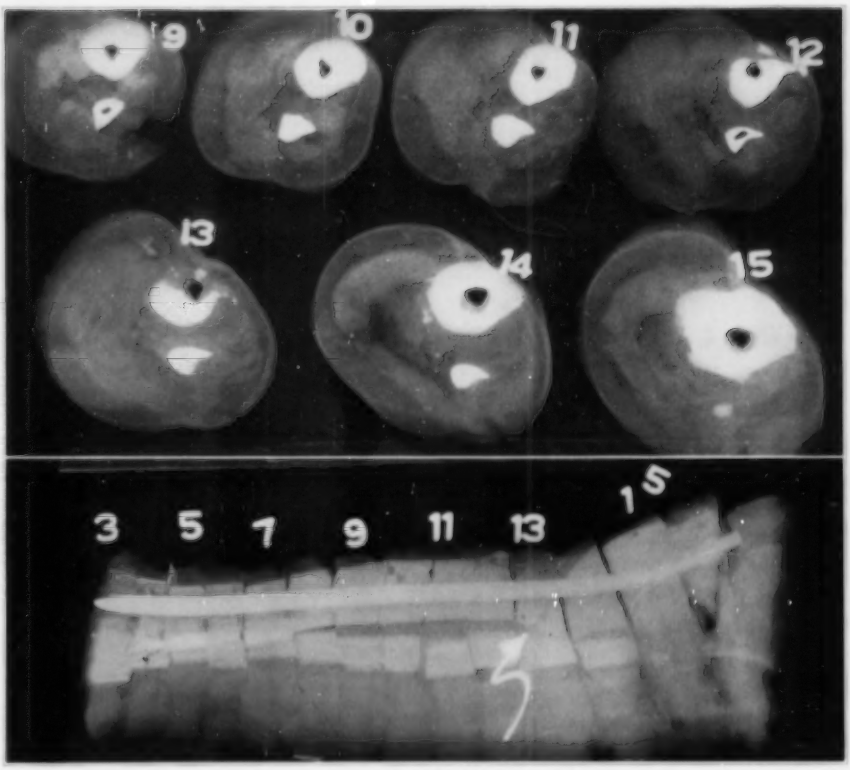

Fig. 11-E

Roentgenograms of a specimen of the fracture. The amputated limb has been cut in sections in the lower half of the picture. Odd-numbered markers were placed to show the levels of the bone. The cross sections with corresponding numbers are shown in the upper half of the picture. The section numbered 13 contained the pseudarthrosis.

applied across the posterior surface of the fracture. Bone-grafting on the posterior aspect was successful in two instances in the presence of persistent infection in the soft parts of the lateral aspect of the leg. Similar cases have been reported [22, 25, 35], but critical observers do not advocate the use of this operation when there is sepsis. In general, the twenty fractures selected for onlay bone-grafting without excision of callus had no missing bone substance; these were similar or only slightly more complicated than those selected for drilling or shingling operations. Nine fractures with sclerosis and necrosis of bone ends were treated by excision of the callus and the opening of the medullary canal before the graft was applied. Regardless of the use of excisional surgery, the fracture site showed new-bone formation before the graft had been completely consolidated or incorporated by the host in approximately half of the fractures in which union occurred. The rate of healing was different in each case, and appeared to depend upon the proliferative reaction of the bone ends following the operation. Intramedullary-rod fixation, in addition to onlay bone-grafting, was used in three old, infected cases of non-union. The Rush pin was used in one case, ordinary stainless-steel tubing in another case, and the Lottes nail in a third case. In all instances, the limb was also immobilized in a toe-to-groin plaster cast. One infected fracture, ununited for over six years, united after twelve months of fixation with an intramedullary nail. Two fractures united promptly in six to nine months, but in one instance sepsis recurred, and the leg was amputated at the request of the patient.

FIG. 11-F

Photomicrograph of tissues found between the compressed bone ends in section numbered 13 of Fig. 11-E. The right-hand side of the picture shows dense hyalinized scar tissue. The top left side of the picture shows chronic inflammatory cells and necrotic connective tissue. There was no fibrocartilaginous callus or new-bone formation.

The results of intramedullary nailing in ununited fractures, as in fresh fractures of the tibia, do not support the use of this method and favor more conservative techniques. Internal fixation, by any mechanical device, did not stimulate healing; it was never an adequate substitute for immobilization in a toe-to-groin plaster cast.

Inlay bone grafts: In twenty-three cases, the fibrocartilaginous callus was entirely or partly excised during the performance of inlay bone-graft operations. In nearly all of these fractures, the defect was less than 0.5 centimeter, and the standard sliding inlay bone graft was placed across the fracture site. The fractures united after periods of further immobilization varying from four to thirty months in sixteen cases, and failed to unite in seven cases. Amputation was performed in one of the failures,—a fracture in which there was latent bone sepsis and recurrence of active infection more than six years after the original injury (Figs. 10-A through 11-F).

Operations for Non-Union with Missing Bone Substance

Fourteen fractures which showed defects measuring two to fifteen centimeters were treated by four different methods: (1) intramedullary massive grafts and supplementary cancellous-bone chips (two cases); (2) synostosis operations (three cases); (3) apposing (sliding) massive grafts (one case); (4) radical leg-shortening (five cases).

Intramedullary massive grafts: Two fractures were treated by massive intramedullary bone grafts of the entire fibula with the addition of iliac cancellous bone chips. An absorption fracture (*Umbauzone*) occurred across the main graft at one year after the operation in one fracture which had had a defect of approximately fifteen centimeters. After an additional onlay bone graft over the *Umbauzone* and after nine additional months in

plaster, the tibia united, but the patient was still in danger of further absorption fractures occurring across another area of the massive graft. In one three-year ununited fracture with a defect of only two centimeters, the result was completely successful fifteen months after the operation.

Synostosis: Surgical operations to produce tibiofibular synostosis were performed in three instances. In two patients with large tibial defects in which active or latent sepsis discouraged bone-grafting at the fracture site, the synostosis produced a certain amount of internal fixation, but the leg had to be protected in a caliper brace. The patients complained of pain over the head of the fibula or near the lateral malleolus. Hypertrophy of the fibula, such as that described in children, occurred very slowly and was hardly appreciable in three years in either patient. The operation was most effective in the third patient in whom there was no significant missing substance; union occurred across the tibial fracture line within nine months. Application of improved surgical methods [16, 21] of producing synostosis would have been more practical than bone-grafting in several other old ununited infected compound fractures in this series.

Apposing (sliding) massive graft: One three-year ununited fracture with a defect of two centimeters was treated by massive half-cylinder sliding grafts. The operation was poorly performed, because of failure to preserve the periosteum and muscle attachments of the intact parts of the bone,—one of the most important aspects of this operation, as it was described by Flanagan and Burem. Excessive dissection of the soft parts, necrosis of bone, and postoperative infection caused this operation to fail. Any operation which similarly destroyed the proliferative capacity of the bone ends failed to produce union.

Leg-shortening operation: Comminuted fractures of the tibia frequently resulted in a certain amount of permanent shortening of the leg in the course of uncomplicated healing. In ununited fractures that had been treated by bone-graft operations which included freshening of the bone ends, shortening of the leg, usually by at least one centimeter, invariably resulted. In five of the eighty-five fractures in this series, the legs were so severely damaged that large areas of skin, muscle, and tendon, as well as of bone, were lost. In these fractures an attempt was made to close the soft-tissue and bone defects by shortening the leg. Between four and seven centimeters of shortening was necessary to bring the bone fragments into contact. The patients subjected to this treatment had also had sepsis and drainage for several years and months or years of skin-grafting in order to convert the open fracture to a closed fracture in which it would be safe to implant a bone graft. Three cases had had failure of one or more previous bone-graft operations. One patient, who was elderly, consented to leg-shortening because he refused to invest his time in a third bone-graft operation which would require several years of healing before the defect was bridged. Leg-shortening operations were thus attempted as the last resort (as an alternative to amputation); they were never recommended in any instance in order to save time. The leg-shortening procedure was accomplished as follows: (1) Through a lateral incision, the superficial and deep scar tissue was excised as widely as possible; (2) the entire fibrocartilaginous callus was excised; (3) the devitalized sclerotic bone ends were completely resected in order to expose normal bone tissue; (4) a segment of the mid-shaft of the fibula was removed through the same incision and was used for an onlay bone graft; (5) the tibial bone ends were brought into direct contact by telescoping the soft parts of the leg and were held together by means of an onlay graft and screw fixation; (6) the severed ends of tendon and muscle which could be identified were trimmed and sutured together. In three cases, the graft was attached to the shaft of the tibia with transfixation screws placed well above and below the fracture line. In two cases, the graft was laid on without screw fixation, but an intramedullary nail was inserted through the tibial tubercle for internal fixation of the fracture. The fractures united in six to nine months in two cases and in twelve to eighteen months in two cases with recurrent sepsis; the fracture failed to unite after twenty-four months in two cases. The process of fracture healing

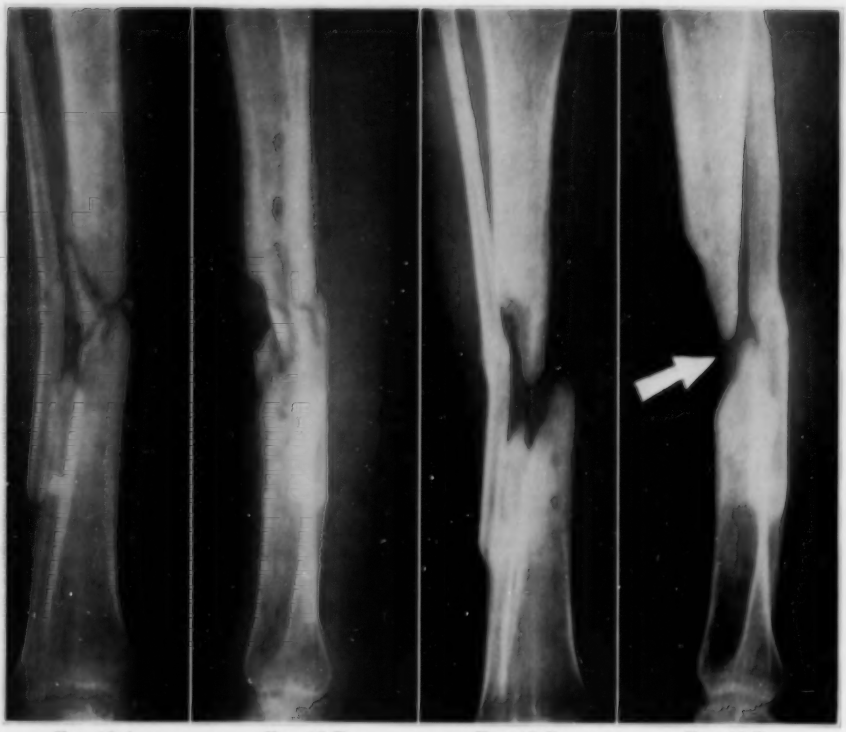

FIG. 12-A FIG. 12-B FIG. 12-C FIG. 12-D

Fig. 12-A: Anteroposterior roentgenogram made eight months after the injury, showing a compound comminuted fracture of the tibia and fibula, following primary open reduction and internal fixation with a bone plate and six screws. There was postoperative sepsis; later the bone plate and screws were removed.

Fig. 12-B: Lateral roentgenogram made eight months after the original injury.

Fig. 12-C: Anteroposterior roentgenogram made seventeen months after the original injury, following extrusion of some of the exposed bone fragments, surgical débridement of other infected bone and soft tissue, and secondary closure of the wound by split-thickness skin grafts and full-thickness sliding skin grafts. The injured leg became approximately one and one-fourth inches shorter than the contralateral leg.

Fig. 12-D: Roentgenogram made after tissue had been removed from between the bone fragments.

following leg-shortening was actually the same as that seen in fresh fractures. Union depended upon the osteogenetic reaction of the bone ends. Failure to heal was primarily due to inactive bone tissue and the recurrence of infection in the site of the fracture. Union occurred promptly in cases of long established non-union if the bone ends had been cut back to good bone tissue with osteogenetic potency and if there was no recurrence of sepsis. The bone graft appeared to encourage the formation of a bridge of bone across the cortex, but the fracture gap had already closed before or closed at the same time that the graft was incorporated in the host bed (Figs. 12-A through 12-H).

Osteotomy of the fibula: The procedure was usually done in combination with excision of the fibrocartilaginous callus and bone ends in order to permit the telescoping and closer apposition of the fracture surfaces. A long oblique saw cut or the excision of a section of the fibula was necessary in order to close the gap in the tibia. In three fractures ununited prior to bone-grafting, the tibia was not exposed, no callus was excised, and the fibula was simply osteotomized through a lateral incision after eight, eleven, or eighteen months of healing in hopes that this measure would permit the muscle forces to compress the fracture gap. In all three, the fibula appeared to heal within four weeks, while the fracture of

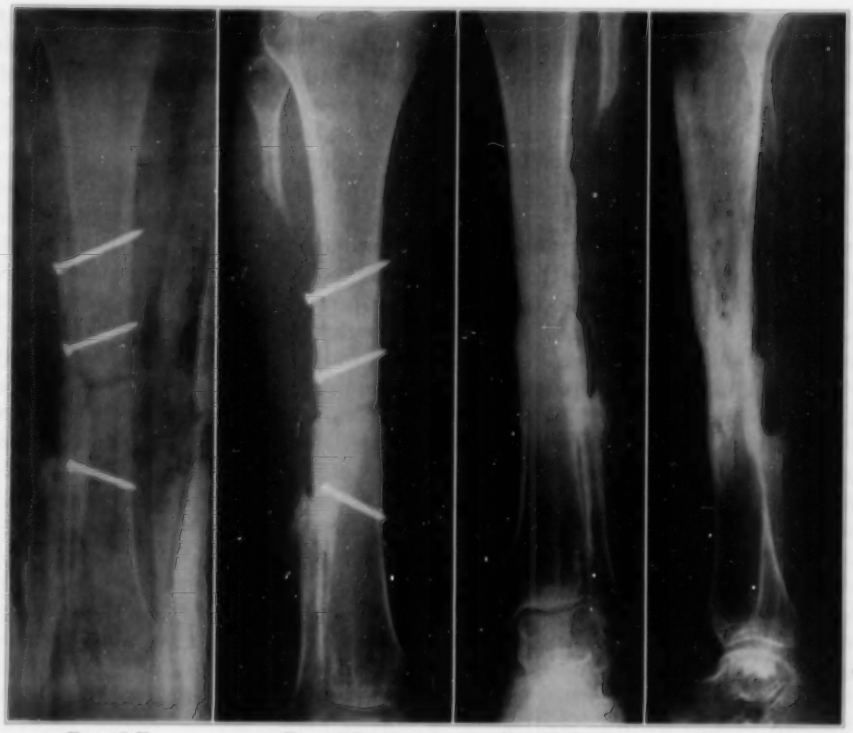

FIG. 12-E FIG. 12-F FIG. 12-G FIG. 12-H

Fig. 12-E: Roentgenogram made eighteen months after the original injury and one month after excision of the fracture site and bone ends, shortening of the leg, and application of an onlay bone graft from the ipsilateral fibula transfixed with three screws and immobilized in a toe-to-groin plaster cast. This operation produced approximately one and a half inches of further shortening, and reduction of the total length of the tibia by approximately two and three-fourths inches.

Fig. 12-F: Roentgenogram made eight months after the operation, showing solid union of the fracture and fusion of the bone graft to the tibia.

Fig. 12-G: Anteroposterior roentgenogram of the fracture made twelve months after the operation. All the metallic fixation had been removed following recurrence of sepsis in the region of the middle screw. Note the solidly healed fracture line and further consolidation of the bone graft.

Fig. 12-H: Lateral roentgenogram of the fracture made at the same time as Fig. 12-G.

the tibia remained ununited. A bone-graft operation was resorted to four to eighteen months later. There is no proof that this procedure is sufficient in itself to produce union of an ununited fracture of the tibia.

DISCUSSION

Fracture healing is one of the body's reactions to injury which is just as active and complete in the highest mammals as it is in the lowest vertebrates. Non-union normally occurs and is not a pathological process in defects in the skull in adult persons. Non-union is always pathological in fractures of the long bones, if the bone ends are in contact and have been properly immobilized. Absolute immobilization is not necessary for the healing of fractures of the ribs, the upper portion of the humerus, or the pelvis where callus formation is normally exuberant. Immobilization is very important however for union to occur in the neck of the femur and the shaft of the tibia, where callus formation is normally scant [29].

The Effect of the Original Injury in Slow-Healing Fractures

Statistical data reported by Henderson and by Owen have shown that delayed healing

and non-union commonly occur in fractures with extensive damage to the bone and the soft parts. The cause of failure of union could have been present at the time of the original injury, or it may have appeared at some later stage of healing. End-result studies show that treatment by open reduction and internal fixation may have adverse effects on bone repair[2, 19, 31, 47]. Obviously, any surgical operation adds further trauma to the original injury. The results in our series of matched cases of united and ununited fractures with similar injuries showed that surgical treatment, which is well tolerated by non-comminuted fractures, simply overloads the capacity of the tibia for repair in comminuted fractures. Comminuted fractures involving more than one centimeter of the length of the shaft, when including its complete circumference, required more than one year to unite. Closed methods, in which a certain amount of shortening was permitted to occur in order to obtain contact of the fragments, seemed preferable to open methods, the risk of sepsis, and the other local conditions unfavorable to bone repair. Extensively comminuted fresh fractures of the tibia should be considered *non-operable* fractures, because of the adverse response to surgical treatment seen in 75 per cent. of the fractures, whether or not union occurred. The term "non-operable" is used here in the same sense that a malignant condition is described as inoperable when surgical treatment is of limited value, harmful, or inferior to non-operative treatment. The more physiological method of treatment of severely comminuted fractures is a two-stage procedure. In the initial stage, the fracture should be treated in a closed plaster cast for one year; in the second stage, when the supernumerary fracture lines normally have been consolidated into one main fracture area, a simple onlay bone graft may be applied, if necessary without the excision of the fibrocartilaginous callus. The second stage requires an additional period of nine to twelve months of immobilization.

It is doubtful that open surgery as primary treatment in fractures of the tibia can be justified by the desire to shorten the periods of hospitalization, immobilization, or disability. The time difference between conservative treatment and the best operative methods in these respects is frequently only one or two months of healing. Disuse atrophy and stiffness of the joints immobilized in plaster are the main disadvantages of conservative treatment. Such sequelae are not preventable, however, by the use of surgical methods. The observations on treatment of fresh fractures in this report corroborate the teachings of Watson-Jones[43], the writings of Charnley, and the recent survey of Carpenter, Dobbie, and Siewers. The biomechanics of fracture healing and soft-tissue-wound healing have often been compared. In both, there can be no doubt that perfect apposition produces earlier repair and that separation results in prolonged healing. Three displaced fractures in this series which were unsuccessfully treated by skeletal traction during the first four to six weeks of healing showed circumstantial evidence of this in incompletely organized hematomata, sterile abscesses, and excessive formation of scar tissue. Immobilization was often difficult to sustain in fractures with severe displacement, loss of bone substance, or sepsis. Immobilization was usually easier to maintain in non-comminuted fractures, and union resulted whenever there was some direct contact between bone ends with good bone tissue. Compression by external force, or by sliding bone plates, in two ununited fractures in this series seemed to have no beneficial effect upon the healing of fractures through such non-compressible tissue as the compact bone of the shaft of the tibia.

Rupture of the Callus: The Premonitory Symptoms and Signs of Non-Union

When bridging of the fracture by new bone does not occur within six to eighteen months, the interior of the callus is likely to show (1) inflammatory and fibrous connective tissue, (2) failure of fibrous tissue to regress, and (3) fibrinoid and hyaline degeneration similar to that seen in old chronic adventitious bursitis. The amorphous material splits, and the reaction creates the following clinical symptoms and signs of rupture of the callus: (1) sudden recurrence of pain and false motion at the site of the fracture, (2) redness and

cyanosis of the skin overlying the area, and (3) local heat and swelling of the leg. These reactions appear a few hours after a minor injury to, or even a slight disturbance of, the fracture, and can be attributed to internal rupture of the callus.

Sudden alterations in the position of the bone fragments are possible only in callus with fibrinoid and hyalin in the fracture gap. A free excursion of the bone ends is hardly ever demonstrable after three months in well reduced, uncomplicated, healing fractures. After any appreciable disturbance, serial roentgenograms of ununited fractures reveal a measurable increase in the width of the fracture gap, sometimes angulation, and even a striking sudden displacement of the bone ends. Rupture of the callus occurs most commonly after such incidents as twisting the leg in a loose or broken plaster case, manual testing of the fracture at times when the casts are changed or windowed, attempts to begin early mobilization of a joint, or early weight-bearing in walking plaster casts or braces intended to stimulate healing. If the fracture had been treated with internal fixation, wires may be torn, transfixation screws may be bent or pulled loose, and steel bone plates may be broken across the fracture line. The action of the leg muscles is not the only force which is responsible for failures of internal fixation. Fibrinoid, like other mucoproteins, seems to imbibe water to produce internal osmotic pressure. The osmotic pressure of mucin is nine times as great as that of albumin. This may build up hydrostatic or hydraulic pressure inside the callus of proportions sufficient to break bone plates and metal appliances which can hardly be bent manually with bending irons.

It is not possible to determine the presence of amorphous material in the callus in roentgenograms prior to the occurrence of these adverse incidents. However, in fractures of the tibia which show no evidence of external bony callus bridging the bone ends and in those in which the accompanying fibular fracture is not healed six months after injury, amorphous material in the callus should be suspected. A scant deposit of bony callus is a relatively common finding in roentgenograms of the lower portion of the tibia before six months of healing and does not necessarily indicate a poor prognosis. In these cases one must guard against early attempts to discontinue plaster immobilization. Complete absence of bony callus at twelve months suggests that fibrinoid degeneration may be present in the fracture gap. The extent to which the pathological changes in the callus are reversible and how this is accomplished is not clear; this remains to be studied further. It is quite certain that many fractures will heal after showing the clinical signs of rupture of the callus. Three control fractures in this series, with all the symptoms and signs of fibrinoid degeneration, and with late development of angulation at the fracture site, were further immobilized in a toe-to-groin plaster cast for six months. These united without any form of surgical treatment. In two other fractures with large defects, the acute symptoms disappeared, but the fracture did not unite with immobilization in plaster or after a long caliper brace was worn for several years. It is probable that during the first year of healing the condition is always reversible and that a pseudarthrosis may not develop if the defect is less than 0.5 centimeter. Rupture of the callus appears to produce irreversible changes when it occurs in fractures with defects of one centimeter or more after eighteen months to two years of healing. Such fractures, if they have been poorly immobilized in walking plaster casts or caliper braces or if they have not been treated by bone-grafting after eighteen months, will show progress toward formation of a false joint.

The Mechanism of Non-Union

Clinical experience with displacement, infection, excessive necrosis of bone, and insufficient immobilization of fractures in different parts of the skeleton clearly shows that the dogmatic statements made in the past about non-union should be regarded with reserve. Any one or any combination of these circumstances is often seen in ununited fractures of the tibia in which callus formation is normally very limited [38, 45]. It is customary to describe gross circumstances, such as distraction, as a "cause" of non-union of

fractures of the tibia[2]. While such a conclusion may appear to be justified in any one case, it is difficult to reconcile it with the normal healing of fractures distracted by hanging casts and by leg-lengthening procedures. Furthermore, clinical impressions do not allow for the finding that, in spite of the widely varying character of the clinical circumstances which lead to non-union, the local structure of the callus in ununited fractures is always the same. Actually no particular lesion has been described, only the products of tissue injury such as necrosis, detritus, and debris[14, 35], and processes such as excessive scar-tissue formation between bone ends[3, 4], myxomatous change[36], and remodeling of the bony callus to produce the architecture of a functioning pseudarthrosis[29, 30, 33].

The observations presented in this report suggest that fibrinoid degeneration of connective tissue is the universal mechanism of non-union. Fibrinoid is invariably found when there is non-union, regardless of the nature of the clinical circumstances or the treatment of the fracture. Fibrinoid might be interpreted as the by-product of inflammation or the result, not the cause, of non-union. It is consistent with the facts to assume, however, that fibrinoid degeneration is a dynamic process and not a static barrier. Actually, the quantity of fibrinoid at any one time is relatively slight, but fibrinoid degeneration of connective tissue in the interior of the callus is a continuous process. It occurs in the space ordinarily occupied by fibrocartilaginous callus. The function of the fibrinoid and mucinous fluid which form when the callus splits appears to be to create and to preserve the false joint space. The origin of glycoprotein, hyaluronates, and other polysaccharides in pseudarthrosis fluid is not known, but they may be degradation products of ground substance and fibrinoid. The cellular and chemical changes concerned with these substances closely resemble those in chronic adventitious bursitis, except that they occur between the bone ends rather than in the subcutaneous area over a bony prominence. Even the etiological factors of these two conditions are the same; they arise with injury and necrosis of connective tissue. They are sustained by inflammation, infection, motion, and friction, and result in an extracellular effusion of mucinous-tissue fluid. Furthermore, the process is inhibited and reversed by immobilization of the part. Recent additions to the knowledge of the histochemistry and histophysiology of connective tissue clearly indicate that continuous fibrinoid degeneration is an important basic concept in orthopaedic surgery. It is the essential process in the function of an arthroplasty, and it is detrimental to achieving an arthrodesis.

Bone tissue is ever being turned over, and bone tissue formed in callus is no exception. Fractures can appear never to stop healing. There is no definite time after which a pseudarthrosis cannot unite simply by prolonged immobilization. Experience has shown, however, that in old cases excisional surgery is more likely to produce union in a reasonable period of time. A new proliferative process begins after any surgical operation and after the implantation of any type of bone graft.

Bone-Graft Operations

The use of bone-grafting for the treatment of fractures was perfected between the First and Second World Wars[10, 11, 15, 26]. Since that time, effort has been directed toward determining the choice of operative technique[1, 6, 25]. Campbell described the effect of bone-grafting on fracture healing in all the major long bones, and advised the onlay type for general use. Equal success has been reported by many others, however, with all variations of intramedullary, inlay, and onlay bone grafts. Before World War II, the pseudarthrosis was commonly excised prior to the implantation of the graft. Fractures in which union occurred without excision of callus were mentioned by Elmsie, Burrows, and more recently by Phemister[35]. The principle of Phemister's onlay bone-grafting procedure without the excision of callus or any form of metallic internal fixation has been widely corroborated by end-result studies on large series of cases of delayed union during the past three years. Phemister[35, 36] noted that the fibrocartilaginous callus was replaceable tissue rather

than a barrier, and he regarded the bone graft as simply a device for internal fixation. Our observations suggest that the function of the bone graft is to promote new-bone formation by induction between the bone ends. If the fibrocartilaginous model is preserved, union may occur beneath the graft before the donor tissue has been incorporated in the host bed. Shingle-chip grafts without internal fixation appear to encourage fracture healing in this way. Union was possible even after a massive graft had been extruded by wound infections in two fractures in which prolonged plaster immobilization was maintained for one or two years postoperatively.

The best results of all operations performed without the excision of the fibrocartilaginous callus in this series were in fractures treated before eighteen months of healing had elapsed and with a minimal bone defect (0.5 centimeter or less). Fractures with a large defect or dense false joint surfaces, which had been formed by walking on the bone ends in braces or casts, required excisional surgery in order to produce union within any reasonable period of time after a bone-graft operation. Observations on matched cases also suggest that many of the fractures in this series successfully treated with bone grafts might have united by continuous plaster immobilization only, if it had been maintained for a period of time corresponding to the period of postoperative immobilization.

The Critical Effects of Sepsis

Infection recurred in seventeen (20 per cent.) of our fractures, approximately the same percentage as that in comparable military cases reported by Kirk in 1938. Penicillin and other antibiotics appear not to have reduced the incidence of latent infection or the recurrence of sepsis in bone-graft operations upon old compound fractures of the tibia. The over-all effect of antibiotics has been to prevent septicaemia and to cause drainage to cease earlier; but antibiotics have also masked the infection. A diffuse increase in the density of the bone structure of the entire shaft in patients with previously infected compound fractures indicated that there was osteomyelitis and that bone-graft operations would fail.

SUMMARY

1. The mechanism of non-union of fractures of the tibia, common to all clinical circumstances of this condition, is fibrinoid degeneration of connective tissue in the interior of the callus. Fibrinoid forms when the bone injury has been extensive, has been complicated by infection, or has been difficult to immobilize. The process appears to be similar to that seen in chronic adventitious bursitis. If motion and friction are not controlled, fibrinoid degeneration continues indefinitely, and a permanent pseudarthrosis may develop. Immobilization acts as a deterrent to the formation of fibrinoid and permits the refilling of the defect with new fibrocartilaginous callus.

2. Fibrinoid is not a simple barrier to osteogenesis; it indicates a defective callus. Fibrinoid fails to draw osteogenesis from the periosteum and endosteum across the fracture gap. According to interpretations of the newer theory of osteogenesis, it lacks the ability of cartilage and fibrocartilage to promote new-bone formation by induction.

3. The effect of open operations on fresh fractures is to increase the volume of damaged bone which has to be absorbed and replaced before the fracture can unite and permit full weight-bearing on the leg. Comminuted fractures of the shaft of the human adult tibia should be considered non-operable fractures during the first six months of healing, because the trauma added by surgery exceeds the normal capacity for bone regeneration in this area of the skeleton.

4. Bone-grafting, without excision of the fibrocartilaginous callus, may be applied successfully in ununited fractures of the tibia before eighteen months of healing. Excision of the pseudarthrosis, osteotomy of the fibula, and telescoping of the fracture ends are advisable in ununited fractures after eighteen months. All of the standard surgical pro-

cedures of onlay, inlay, or intramedullary bone grafts are capable of producing union with the aid of one additional year of immobilization of the fracture, but the success of the operation is determined by the proliferative reaction of the bone ends, not the bone graft. If the bone ends are in close contact, the function of the graft appears to be that of an inductor.

5. Recurrence of sepsis is the chief cause of failure of all types of bone-graft operations. Roentgenograms which show a diffuse increase in density of bone tissue three or four centimeters above and below the fracture line indicate latent sepsis. In such cases six months, or even two years, without drainage is not a safe period of waiting to permit a bone-graft operation. Only synostosis operations which avoid the fracture site are free of risks of further damage to the bone ends by infection.

6. Radical leg-shortening procedures are an alternative to amputation and may be applicable in old ununited fractures with large soft-tissue defects after repeated failure of bone-grafting operations.

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DISCUSSION

Dr. John J. Flanagan, Newark, New Jersey: Many clinical conclusions can be drawn from this extensive study. As the authors have stated, a distraction of 0.5 centimeter of the fractured margins of the tibia needs approximately twelve months of healing for a bony bridge to form, while a separation of one centimeter requires twenty-four months or more of healing for a bridge to form, if bony union occurs.

Many delayed unions and non-unions are the result of careless or inadequate initial treatment of the fractured tibia at the time of the original accident. In retrospect, it is possible that many delayed unions and non-unions, reported here and elsewhere, could have been avoided by more accurate reduction of the fragments, by meticulous care and treatment of the compound wounds, and, if skeletal traction was required, by avoidance of distraction at the fracture site, with positive and complete immobilization of the affected bone and the adjacent joints.

In simple fractures of the tibia, the tried-and-true method of closed manipulation and reduction is still our most efficient means of treatment. The use of a Kirschner wire through the calcaneus for the purpose of strong skeletal traction is of great assistance in obtaining accurate reduction, the wire being removed after

the application of a toe-to-groin circular plaster cast. Early open reduction in fractures of the tibia is rarely indicated, and wide surgical dissection adds additional surgical trauma to the already impaired blood supply; delayed union or non-union frequently results.

In compound fractures, when the fractures are multiple and reduction is difficult, the use of intramedullary pins or nails may be occasionally indicated. With the aid of antibiotics, we can be more bold than we were before World War II.

When delayed union or non-union seems inevitable or when it is anticipated, I believe we should not wait twelve to eighteen months or more before planning surgical intervention. In many cases, we will know in a period of three to four months following the injury whether delayed union or non-union will ensue. This is the time to act. We all know the results, both from the standpoint of economics, as far as the patient is concerned, and from the standpoint of permanent impairment of function, especially of the ankle joint and foot, following prolonged immobilization and inactivity. In such cases, when the bone ends are in good or fair alignment at the site of fracture, the least damaging operation, as far as circulation to the bone ends is concerned, is an operation developed one hundred years ago by Brainard—namely, drilling of the bone ends.

An incision over the site of delayed union of the fracture is made, the skin being cautiously reflected. Through at least six openings on either side of the fracture, on the superficial anteromedial surface experiosteally, the site is drilled through and through with a long electric drill bit. Irrigation with saline solution is done and care is taken to avoid burning the bone at the site of the bone channels. The drill bit is passed across the fracture site in every conceivable plane, at least thirty to forty times or more in both directions.

I fully agree with the authors that, with few exceptions, the interposing degenerated fibrous tissue between the bone ends should not be removed at time of surgery, either bone-drilling or bone-grafting. If this mass is removed, further surgical trauma and impairment of circulation results.

In fractures in which the bone ends are in fair alignment and this conservative bone-drilling operation seems inadequate, the use of an onlay cortical bone graft or a cancellous autogenous bone graft will frequently stimulate osteogenesis. Again, the interposing layer between the bone ends should remain unmolested, and the periosteum or muscle tissue should be elevated from the tibia only at the site planned for the onlay bone graft. The bed for the graft is prepared by denuding the superficial cortex of the bone on either side of the fracture site. Occasionally, if indicated, both operations may be combined successfully.

When actual non-union exists, with loss of bone substance, more radical bone-graft surgery, with massive autogenous grafts, is indicated. However, once we accept non-union as a fact, before resorting to radical bone-graft surgery, all rigid immobilization should be removed from the affected lower extremity, and the leg should be fitted with a short-leg brace, with a wide leg cuff of leather and a free ankle joint. Extensive daily reconditioning of the extremity, with physical therapy, consisting of mild heat either dry or whirlpool, followed by intensive massage and graduated active exercises of the adjacent knee and ankle joints and the foot, should be carried out. By these daily treatments, in addition to repeated daily active exercises of the affected atrophied muscles of the extremity, mobilization of the stiff knee and ankle joints and of the foot is accomplished with the re-activation of the stagnant circulation to the affected bone. This preoperative reconditioning should extend over a period of from four to twelve weeks prior to surgery. There is no danger of damaging the soft tissues, nerves, and blood vessels about the ununited tibia, as the bone ends are firmly embedded in the degenerated fibrous tissue mass.

At operation, caution should be exercised to maintain as adequate a local blood supply as possible at the site of operation by avoiding the unnecessary detachment of periosteum and muscle tissue.

I fully agree with the authors that, when radical bone-graft surgery fails to bring about union, resecting of the bone ends back to normal bone, in order to gain contact of apposing healthy bone ends, will frequently obtain union. This is a worthy procedure when previous radical bone-graft surgery has failed and when foot and ankle are essentially normal. Union of the tibia with leg-shortening is certainly preferable to amputation.

Dr. Granville A. Bennett, Chicago, Illinois: Just ten years ago, I had the privilege of discussing fracture healing at the Annual Meeting of this Academy. The data available to us then indicated that the best opportunity for fracture healing required (1) that the fractured bone fragments should be placed in the most advantageous position at the earliest possible moment, (2) that once satisfactory alignment and close apposition have been obtained, the part should be immobilized, and (3) that immobilization should be maintained until union has been established or until it has been determined that healing has failed to take place and that other therapeutic measures are required. In so far as I am aware, these simple principles still hold.

Today, Dr. Urist and his associates have presented their conclusions concerning the pathogenesis of delayed union and non-union. They have recognized that the circumstances which account for delayed union or non-union frequently include displacement of fractured ends, fragmentation of bone at the fracture site, missing bone substance, surgical dissection of the fracture area, sepsis, and the implantation of metallic appliances. In their detailed study of this large series of fractures, the authors have attempted to uncover the underlying basic mechanisms which are responsible for imperfect healing of fractures. To do this, the authors have drawn most effectively upon recently acquired information concerning the composition and behavior of

(Continued on page 980)

VERTEBRA PLANA (CALVÉ'S DISEASE) DUE TO EOSINOPHILIC GRANULOMA *†

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In an unpublished report to a group of orthopaedists (Correspondence Club Letter) in January 1950, one of us (Compere) described two patients with eosinophilic granuloma of the spinal column; in each, a single vertebral body was involved. In one patient (referred to as Case 3 hereinafter), the lesion healed with complete flattening of the vertebral body. In the roentgenograms the lesion presented an appearance which was similar to that seen in the cases of vertebra plana reported by Calvé at a meeting of the British Orthopaedic Association in Bologna, Italy, on September 22, 1924. In the unpublished letter the opinion was expressed that eosinophilic granuloma *is the cause of vertebra plana*. The two patients reported on in the Correspondence Club Letter, a third observed at the Mayo Clinic, and a fourth encountered subsequently at Children's Memorial Hospital in Chicago are herewith presented in support of the theory that vertebra plana is caused by eosinophilic granuloma.

Calvé, in his report, included a case which had been described to him by Brackett of Boston. Brackett's patient, who was seven years old, first showed a disinclination for prolonged play. He became fatigued easily. Later there were muscle spasm, rigidity of the spinal column, night cries, and prominence of one spinal process. Calvé's patient was two and a half years old. The onset of the condition had been gradual, with stiffness, loss of interest in play, pain in the back, and the appearance of a small gibbus or "knuckle" produced by the prominence of a single spinous process. Calvé preferred the use of the term "osteochondritis" to describe the process. Buchman, however, suggested the name "vertebra plana". Since the publication of Calvé's original description, many cases of vertebra plana have been reported.

Sir Thomas Fairbank, in a lecture delivered on October 10, 1952, called attention to a case reported by Snapper who described a patient, four years old, with multiple eosinophilic granuloma. Snapper included a roentgenogram of the spine which showed collapse of the sixth thoracic vertebral body. He made no suggestion regarding the possible connection between vertebra plana and multiple eosinophilic granuloma. Fairbank, however, stated, "Personally, I feel that eventually vertebra plana will be proved to be one manifestation of granulomatosis, and not a clinical entity". Other than this, no theory of etiology different from Calvé's has been presented.

The present report demonstrates eosinophilic granuloma in four patients with typical vertebra plana.

Among the observations reported by Calvé, which were noted in each of our four patients, were the following:

1. Only one vertebra was involved (in two patients, there were also lesions in one or more ribs);

* Received for publication on December 18, 1953.

† Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 25, 1954.

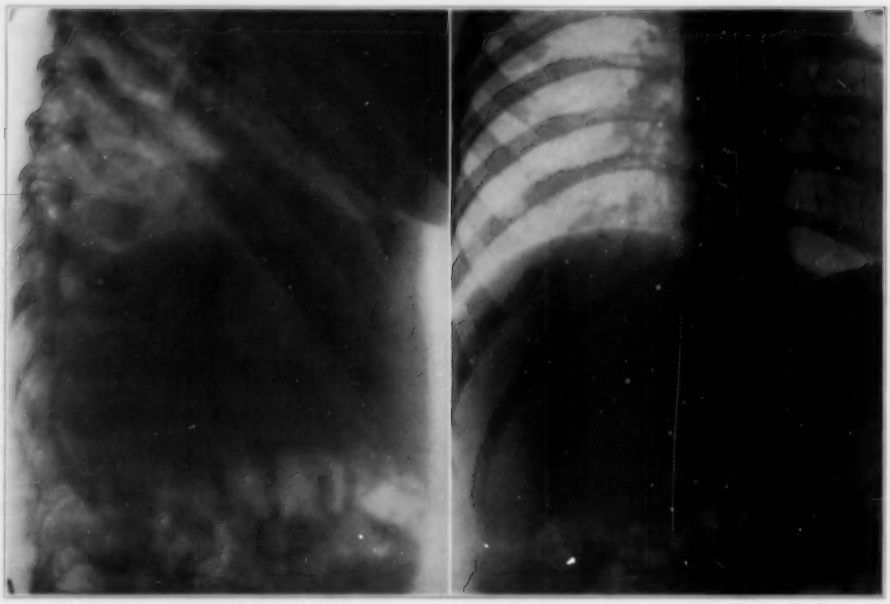

FIG. 1-A FIG. 1-B

Case 1, a boy, fourteen months old. Lateral and anteroposterior roentgenograms of the thoracic and lumbar portions of the spinal column made on August 23, 1948, seven weeks after the onset of symptoms. Note vertebra plana of the eleventh thoracic vertebra and the osteolytic involvement of the tenth rib on the right.

2. Adjacent discs were intact above and below the diseased vertebra;

3. Disc spaces were actually about a third wider than the next spaces above and below (except in our Case 1 in which the disc space above was narrowed);

4. The vertebrae which had been completely flattened remained dense cortical discs and resembled the edge view of a silver dollar.

Calvé concluded, "The affection . . . is, I believe, to the spinal column what coxa plana is to the hip, and what Koehler's disease is to the foot". We believe that Calvé's disease is a syndrome found in young children and is characterized by pain in the back, with the usual signs of muscle spasm, tenderness, and rigidity. The roentgenographic findings, in the typical case, reveal the involvement of one vertebral body by a process that produces a dense-appearing vertebra which is evenly flattened front and back and simulates the edge view of a silver dollar.

REPORT OF CASES

CASE 1. A boy, fourteen months old, was seen at the Mayo Clinic in August 1948, because of pain in the back. The mother stated that seven weeks prior to examination he had complained of pain in his back when he fell or when he sat down hard and that he had cried more than usual. His development had been normal up to that time. He had walked at the age of eleven months. He had begun gradually to stop walking as his pain increased. He had been hospitalized in his home community for one week because of the pain, and at that time a low-grade fever had been noted. Roentgenograms, which were made available to us at a later date, revealed, three weeks after the onset of symptoms, narrowing of the intervertebral space between the tenth and eleventh thoracic vertebrae and an osteolytic involvement of the right tenth rib. The boy had been discharged from the hospital, even though the pain had persisted. He had lost his appetite, would not sit in his high chair or on the toilet seat, and had cried frequently. Seven weeks after symptoms began, roentgenographic examination had revealed the presence of an early collapse of the eleventh thoracic vertebra (Figs. 1-A and 1-B) and an osteolytic involvement of the right tenth rib. He was referred to the Mayo Clinic for further investigation and treatment.

Physical examination disclosed a fairly well nourished child who did not want to sit, apparently because of pain. His temperature was normal. There was flattening of the spinal column in the region of the tenth, eleventh, and twelfth thoracic vertebrae. Tenderness was present in this region, and muscle spasm was

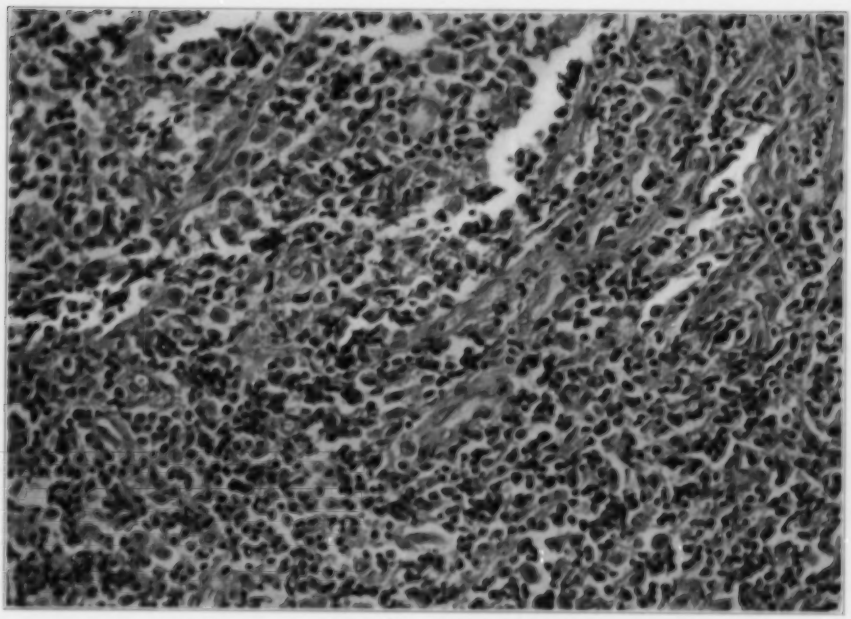

FIG. 1-C

Fig. 1-C: Appearance of biopsy material from the tenth rib on the right (hematoxylin and eosin stain; × 250). The diagnosis of eosinophilic granuloma was made.

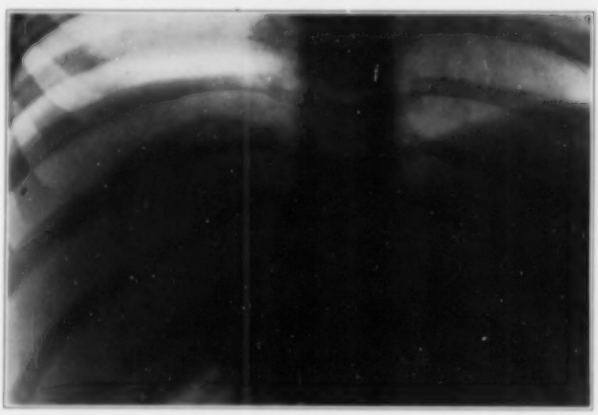

FIG. 1-D

Fig. 1-D: Anteroposterior roentgenogram made on October 4, 1948, five weeks after radiation therapy had been begun, shows partial healing of the lesion in the rib.

evident. Otherwise, the results of the physical examination were negative. Laboratory examination gave negative results except for the disclosure of slight secondary anaemia.

Roentgenographic examination of the spinal column and ribs disclosed almost complete destruction of the body of the eleventh thoracic vertebra and an expanding osteolytic involvement of the posterior portion of the right tenth rib. The diagnosis of Calvé's disease of the eleventh thoracic vertebra and either xanthoma or eosinophilic granuloma of the right tenth rib was made.

On August 26, 1948, one of us (Coventry) obtained material from this rib by means of open biopsy; the diagnosis of eosinophilic granuloma was made by the surgical pathologist (Fig. 1-C). Cultures of the material from the rib revealed no growth. The vertebral body was not subjected to biopsy. The child's postoperative course was satisfactory. When the wound had healed, he was fitted with a Taylor brace. Roentgen therapy was advised and, in September 1948, he was given his first course of radiation. He experienced marked subjective improvement, but the pain recurred in the fourth week after treatment. He received the second course of therapy at that time, again with improvement in his general condition and lessening of pain. Roentgenographic examination at that time disclosed partial healing of the destructive lesion in the rib (Fig. 1-D). In November 1948, he received his third course of radiation therapy.

The child began to be more active and to walk with less difficulty. When he was examined again in February 1949, six months after his original visit to the Clinic, he had experienced no pain in the previous month and was walking quite well. Roentgenographic examination revealed marked improvement in the costal lesion (Figs. 1-E and 1-F). The eleventh thoracic vertebra appeared to be more dense and slightly

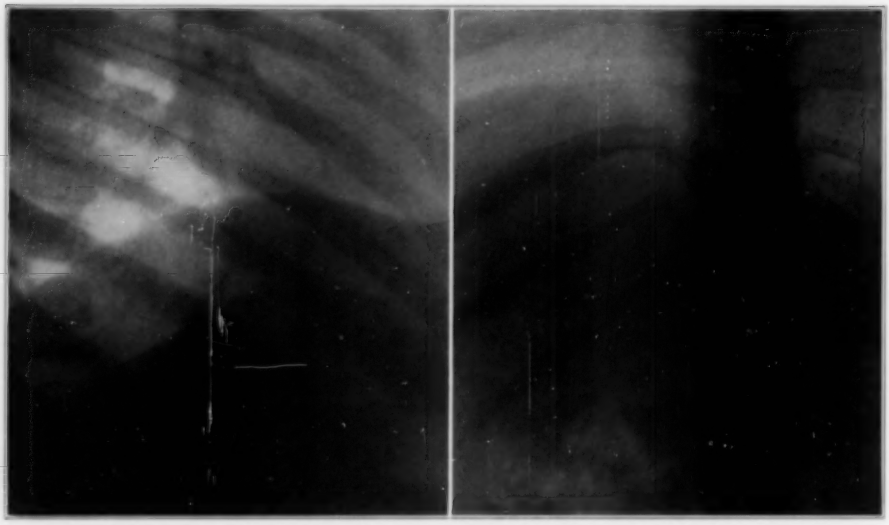

FIG. 1-E FIG. 1-F

Lateral and anteroposterior roentgenograms made on February 14, 1949, seven months after the first examination and six months after the first course of radiation therapy. Healing of the lesion in the rib is almost complete. The vertebra is more dense and is slightly fragmented.

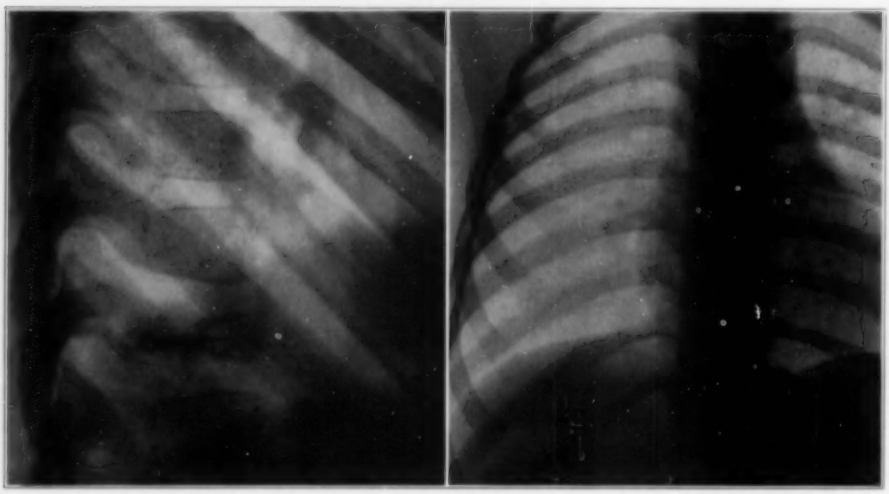

FIG. 1-G FIG. 1-H

Roentgenograms made on November 25, 1952, four years and three months after the diagnosis of vertebra plana due to eosinophilic granuloma was made. The patient was without symptoms, the vertebral body was enlarging, and the lesion in the rib had healed.

fragmented. Three months later he began having increased pain in his back and stopped walking for a few days. Examination at this time disclosed nothing unusual. There were no abnormal reflexes in the lower extremities. Roentgenographic examination indicated that the lesion in the rib had apparently healed but that no change had occurred in the vertebra. He began walking again in a day or two and seemed to experience no more pain. He was re-examined in September 1949, in February 1950, and in December 1950, at which times additional roentgenograms were made. Roentgenograms were last made in November 1952 (Figs. 1-G and 1-H). He had been allowed to remove his Taylor brace six months before. He was active and was developing normally, and he had no complaints of pain and no tenderness. There was minimal rounding of the back with some compensatory lumbar lordosis, but there was no true deformity (Figs. 1-I and 1-J).

CASE 2. On November 16, 1948, a girl, seven years old, was referred to one of us (Compere) because of stiffness in her back. The patient's grandfather, a physician, was afraid that she had tuberculosis. She com-

plained very little of discomfort. Examination revealed considerable stiffness of the back due to muscle spasm. There was also tenderness upon percussion or digital pressure in the vicinity of the spinous processes of the seventh to ninth thoracic vertebrae. Neurological examination disclosed no abnormality.

Roentgenograms showed partial destruction of the central portion of the eighth thoracic vertebra, with some collapse of the vertebral body which was more pronounced on one side than the other (Figs. 2-A and 2-B). In the lateral roentgenogram (Fig. 2-A), the marked lytic nature of the lesion was apparent. Almost all of the vertebral body except the superior and inferior cortical plates had been destroyed or absorbed. The concentrations of alkaline and acid phosphatase were normal, as was the sedimentation rate. The tuberculin reaction was negative. The roentgenographic appearance of the thorax and skull was normal. On November 23, 1948, open biopsy was done, and the laminae and spinous processes of the seventh to ninth thoracic vertebrae were exposed. The laminae, pedicles, and centrum of the eighth thoracic vertebra had been, in part, replaced by a slightly sticky, friable granulation tissue which was grayish purple with yellowish flecks. Microscopic study showed a typical eosinophilic granuloma (Fig. 2-C).

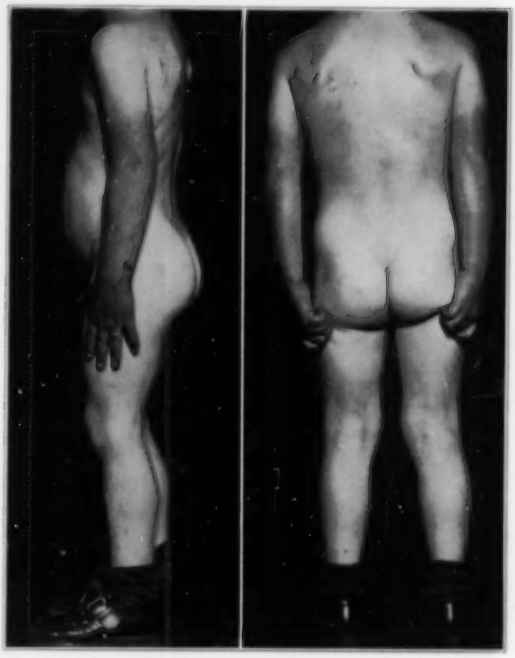

FIG. 1-I FIG. 1-J

Appearance of the boy three years after the onset of vertebra plana due to eosinophilic granuloma. There is no obvious deformity.

A body cast was applied to maintain extension. Windows were made in the cast over the involved spinous processes, and roentgen therapy was administered. The cast was removed February 11, 1949. Roentgenograms made on March 11, 1949 (Figs. 2-D and 2-E), showed good regeneration of the involved vertebral body, and roentgenograms made eighteen months later showed further regeneration (Figs. 2-F and 2-G). This patient has continued to be well. There has been no increase in the deformity. Roentgenograms made four years after the biopsy show completely normal-appearing bone with no recurrence of the disease process. The only evidence, at that time, that any pathological process had been present was the slightly wedged body of the eighth thoracic vertebra.

CASE 3. A boy, six years old, was seen in consultation with Dr. Welford at Children's Memorial Hospital, Chicago. On July 17, 1949, this patient had fallen over a picket fence at the zoo. Several days later, after falling from a bicycle, he had complained of pain in his thorax. Since the initial injury his mother had observed that he walked with a slightly stooped posture, complained of backache, and did not care about playing with his friends. He had been treated by the application of hot packs because of a presumptive diagnosis of poliomyelitis, but roentgenograms revealed the partial collapse of the fifth thoracic vertebral body. It was thought that this represented a fracture (Figs. 3-A and 3-B).

Examination revealed a slight prominence of the posterior spinous process of the fifth thoracic vertebral body and tenderness to percussion over this process. It was the opinion of one of us (Compere) that this was probably an eosinophilic granuloma, and a biopsy of the tumor was done. The material removed for biopsy by means of a small bone punch and curette contained granulation tissue which confirmed the diagnosis of eosinophilic granuloma. A spine fusion from the fourth to the sixth thoracic vertebrae inclusive was carried out at the time of biopsy. The patient was given roentgen therapy, and a body cast was worn for four months. On December 19, 1949, when the cast was removed, roentgenograms showed healing of the lesion but loss of most of the body of the fifth thoracic vertebra. The cortical portion of the bone remained as a dense white line in the roentgenogram, similar in appearance to that in the cases reported by Calvé.

This patient has continued to be well, and at the last examination, on August 25, 1952, the appearance in the roentgenogram was exactly the same as it had been on December 19, 1949 (Figs. 3-C and 3-D). The child is normally active and has no complaints referable to the spinal column.

CASE 4. A boy, two years and ten months old, was admitted to the Children's Memorial Hospital, Chicago, on June 14, 1951, with the complaint of abdominal pain of a month's duration and unwillingness to

FIG. 2-A FIG. 2-B

Case 2, a girl, seven years old. Lateral and anteroposterior roentgenograms, made on November 16, 1948, show partial destruction of the eighth thoracic vertebra.

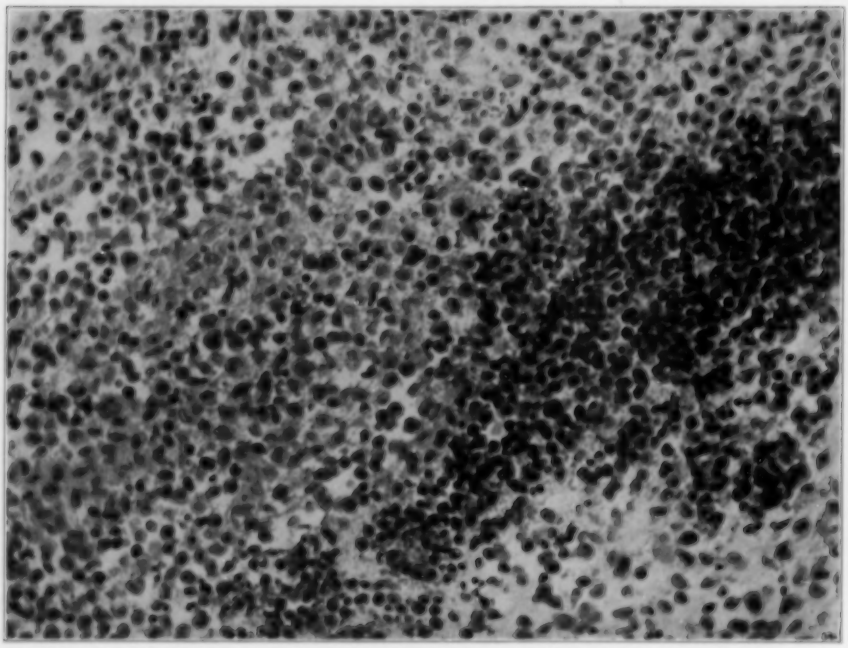

FIG. 2-C

(*See page 975*)

Fig. 2-C: Appearance of material removed from the eighth thoracic vertebra (hematoxylin and eosin stain; × 300). The diagnosis of eosinophilic granuloma was made.

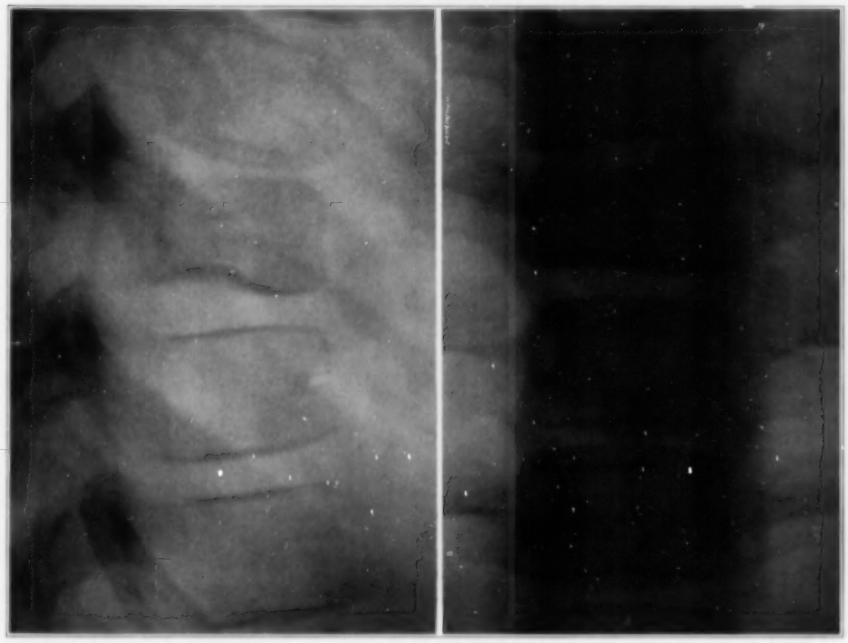

FIG. 2-D FIG. 2-E

Roentgenograms made four months after radiation therapy had been instituted. There is regeneration of the bone.

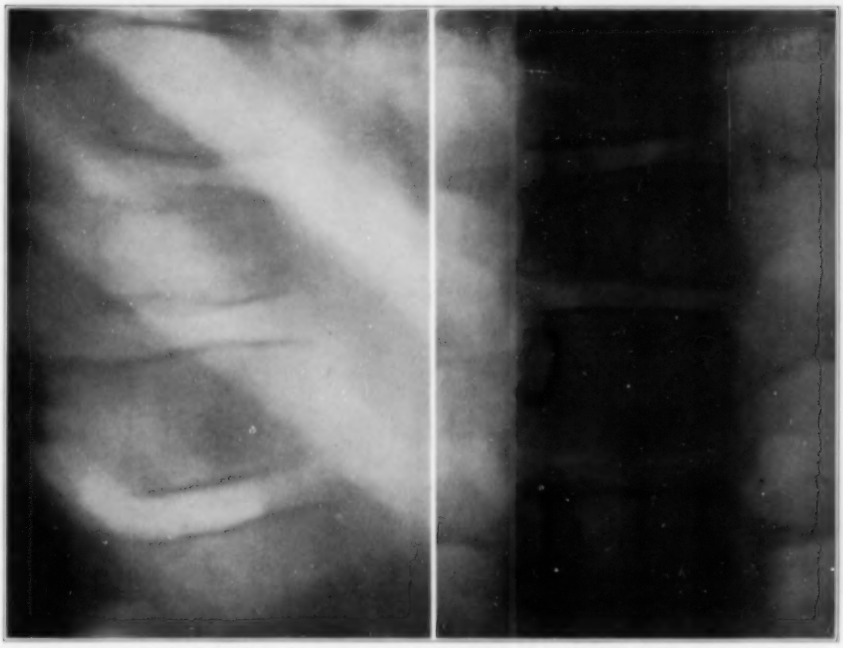

FIG. 2-F FIG. 2-G

Roentgenograms made eighteen months later.

play. He appeared to be clumsy and had fallen down several times. Enuresis had been noted a week before admission. On the morning of admission a temperature of 103 degrees Fahrenheit was recorded. The past

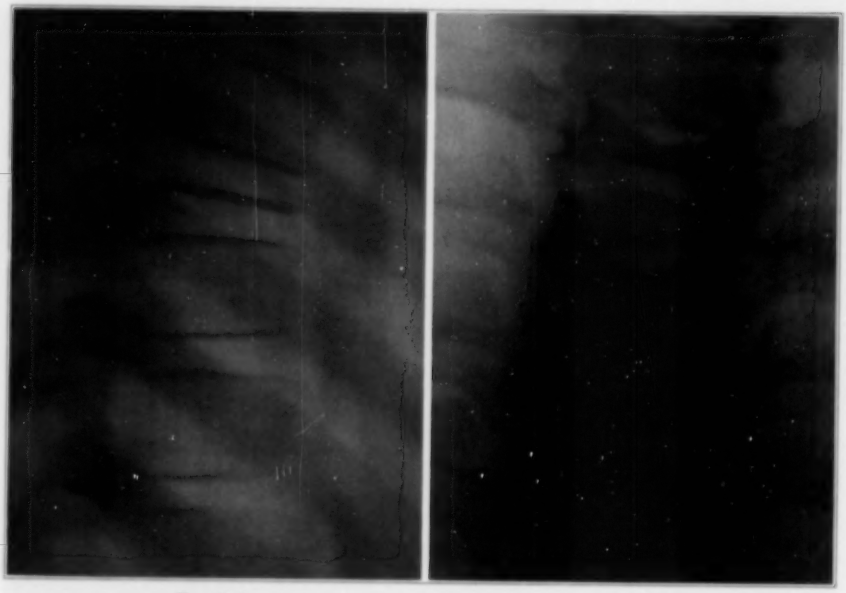

FIG. 3-A FIG. 3-B

Case 3, a boy, six years old. Roentgenograms show osteolytic involvement of the fifth thoracic vertebral body.

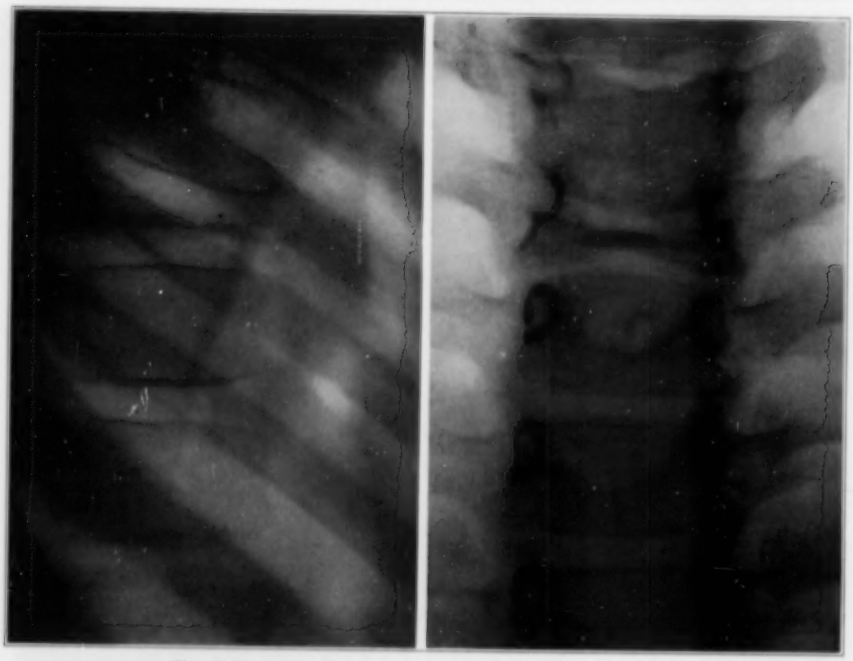

FIG. 3-C FIG. 3-D

Roentgenograms made on August 25, 1952, three years after the onset of symptoms. The patient had been treated by spine fusion and radiation therapy. The vertebral body was still a thin black-appearing disc. The child had no symptoms.

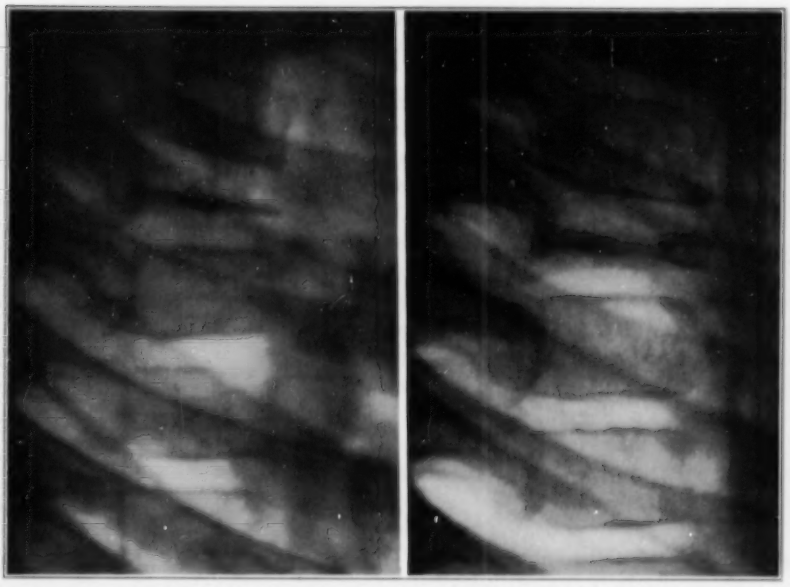

FIG. 4-A FIG. 4-B

Fig. 4-A: Case 4. Roentgenogram of the spine of a child, three years and two months old, shows vertebra plana of the fourth thoracic vertebra.

Fig. 4-B: Roentgenogram made on March 26, 1953.

history revealed that this child had not received any vitamin or cod-liver-oil preparations. The mother, father, and five siblings were all living and well.

Physical examination disclosed stiffness of the neck and back, cervical adenitis, and large inflamed tonsils. The laboratory findings were normal. Roentgenograms of the thorax revealed no evidence of pulmonary involvement. The spinal fluid was clear, there were three polymorphonuclear cells per cubic millimeter, and the results of the Pandy test were negative. A diagnosis of acute tonsillitis was made; this was treated with penicillin and gantrisin. The child was discharged from the Hospital three days after the beginning of treatment.

On November 8, 1951, somewhat more than four months after the first admission, the child was readmitted to Children's Memorial Hospital because of difficulty in walking, pain between the shoulders and in the small of the back, and frequent falls. On the day of admission he refused to try to walk at all. From the time of the first admission until the second there had been a weight loss of one pound.

Physical examination at the time of the second admission disclosed a normal temperature, a rigidly stiff neck and back without paralysis, and normal reflexes. Laboratory findings at this time were also within normal limits.

Roentgenograms revealed a collapse of the fourth thoracic vertebral body (Fig. 4-A). Re-examination of the roentgenograms made on June 15, 1951, disclosed the fact that a partial collapse of this vertebra had been present but had been overlooked at the time of the first admission. In other roentgenograms cystic lesions of the left clavicle and the left seventh rib were seen. Resection of one and a half inches of the left seventh rib was carried out on October 9, 1951. Microscopic sections revealed eosinophilic granuloma. A course of roentgen therapy to the visualized lesions in the bone very promptly relieved the patient of his symptoms. He has continued to be well since shortly after completion of the treatment, and, on March 26, 1953, the vertebral body showed partial regeneration (Fig. 4-B).

Vertebra plana is relatively rare. Only twenty-seven cases had been reported in the literature when Mezzari summarized the cases up to, and including part of, 1938. Usually, the symptoms in Calvé's disease are of relatively short duration with rapid progression. A spinal gibbus may be present, and tenderness, spasm, and limited motion of the back may be found. Roentgenographically, in the early stages, the lesion is revealed to be osteolytic, and the body of the vertebra disappears. Later, one may see a flattened, dense-appearing vertebral body which is usually flattened evenly front and back and may not be wedge-shaped. In Cases 1, 3, and 4, the typical silver-dollar appearance of the vertebral

body was present. In Case 2, it is possible that the process had been arrested by roentgen treatment before collapse of the body occurred. The disease occurs most frequently between the ages of four and nine years.

Treatment should include splinting and rest. Gradually, the lesion becomes less painful. The vertebral body may re-ossify, with little loss of height and with strong bony trabeculation. Recovery, according to this regimen, requires one to three years. Roentgen therapy was used in each of the four cases reported herein, and healing was rapid with relief of symptoms in a matter of months.

Several authors have considered Calvé's disease to be a form of avascular necrosis similar to that seen in the head of the femur (coxa plana). In the four cases presented in this paper the lesion was caused by eosinophilic granuloma. It is our feeling that, while other conditions may cause collapse of a single vertebra in young children, the clinical and roentgenographic picture is not similar to that in the cases presented. Certainly this clinical entity is not due to tuberculosis, metastasis, neuroblastoma, or fracture from trauma. These processes give a different clinical and laboratory picture and prognosis than does Calvé's disease as we have interpreted it.

Mezzari reported in 1938 the postmortem findings in the case of a child suffering from Calvé's disease. He had observed this eight-year-old boy for a year, and the roentgenographic picture, at the time of death from an intercurrent infection, was one of regeneration of the body of the twelfth thoracic vertebra. The cancellous bone of the involved vertebra appeared microscopically to be of normal structure, except that the trabeculae were larger than the normal. Mezzari expressed the belief that the involved vertebra represented newly formed bone. Significantly, there was no evidence of eosinophilic granuloma of this vertebral body, but it must be remembered that the patient had had symptoms for a year and a half prior to death and that roentgenographically the involved vertebral body appeared to be healing when he died.

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DISCUSSION

Dr. J. William Hillman, Nashville, Tennessee: Dr. Compere, Dr. Johnson, and Dr. Coventry have presented a stimulating clinical report which assigns an exact cause to four cases of vertebra plana. This paper is of significance in that it represents another forward step in the refinement of clinical accuracy, which began thirty years ago, when it was recognized that vertebra plana is not a manifestation of tuberculous spondylitis. The authors have suggested that the disease is caused by eosinophilic granuloma rather than by an osteochondritic process as described by Calvé. This conclusion was reached after the very careful study of four patients, including examination of biopsy material. The morphological changes of vertebra plana seem to be in accord with the behavior of eosinophilic granuloma, particularly in the rapidity of the destructive phase.

At the same time, the observation is possibly in order that these changes are not pathognomonic of any single entity but may be produced by other rapidly osteolytic lesions. The following case is presented to illustrate from my very limited experience the reluctance one must have in assigning an etiological significance to the roentgenographic appearance of a vertebral lesion (Figs. 1-A and 1-B).

The patient was eight years of age. There was complete loss of height of the tenth thoracic vertebra. The adjacent intervertebral-disc spaces were quite wide, and there was a remnant of condensed bone visible. A roentgenogram made one month before showed a completely normal spine. The child was not ill; the only complaint or physical finding was the loss of mobility of the spine, as observed by the school teacher. Laboratory studies were not helpful. A costotransversectomy was performed; this proved the condition to be

FIG. 1-A

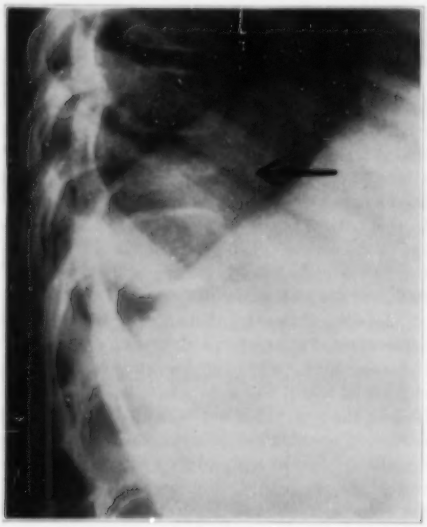

FIG. 1-B

caused by a highly malignant undifferentiated sarcoma. I should have mentioned earlier that among the preoperative diagnoses which were considered was eosinophilic granuloma.

It would have been of great value if Dr. Compere and his associates had commented upon the clinical significance of the statement made at the conclusion of the paper, "It is suggested that Calvé's disease or vertebra plana is caused by eosinophilic granuloma".

It is to be expected that the authors and orthopaedic surgeons generally will continue the current trend toward being inquisitive about the precise nature of bone lesions. When larger numbers of cases of this type are assembled it will be interesting to see if there are not many types of osteolytic processes which may appear rapidly in the vertebrae of children and produce vertebra plana. There is no assurance yet that some cases of vertebra plana are not, as Calvé suggested, an osteochondritis or other disturbance of orderly growth. The cycle may yet be completed when, in the future, someone in this assembled group demonstrates a case of vertebra plana caused by tuberculous spondylitis.

DR. SAMUEL B. PREVO, NASHVILLE, TENNESSEE: My first criticism of this paper is concerned with the definition of terms. I would be interested in knowing whether by vertebra plana is meant any flattening of a single vertebral body, or does the term apply to the flattened sclerotic body described by Calvé in 1925. If it is considered to be the former, I find it difficult to agree with the authors' conclusions, since it is conceivably possible that one could encounter osteolytic lesions in single vertebral bodies in neoplastic or hematogenous osteomyelitic lesions which, in their early phase, might present such a picture. If the authors consider vertebra plana to be the flattened sclerotic vertebral body, it appears to me that they are observing a healed or healing lesion and that the diagnosis becomes a retrospective one and of no clinical significance in differentiating osteolytic vertebral-body lesions. The treatment of these might vary considerably from the conservative approach to eosinophilic granuloma. This, then, would bring us back to the already established principles in regard to destructive bone lesions, which point to the advisability of obtaining an adequate biopsy of lesions that cannot be satisfactorily diagnosed by supportive evidence of disease elsewhere in the body.

My only other criticism of this well organized paper is the subscription of the authors to the policy of canonization of first describers of conditions by referring to the condition as their disease. At the risk of being called an iconoclast, I suggest that anatomical and pathological nomenclature be retained in classifying this condition and that the use of Dr. Calvé's name be avoided. I also feel that a more accurate title for this paper would have been "Eosinophilic Granuloma: A Cause of Vertebra Plana". In spite of these superficially critical remarks, it has been a pleasure to study and to discuss this paper in which Dr. Compere, Dr. Johnson, and Dr. Coventry have added another facet to the already numerous articulations of eosinophilic granuloma.

DR. COMPERE (closing): I was told only a short time ago that your present presiding chairman, Dr. Ingram, has a patient with two vertebral lesions similar to those presented here which have proved to be eosinophilic granuloma. Since vertebra plana is either rather rare or produces few or no symptoms later in life, it is comparatively rarely recognized and diagnosed. As has been related, this lesion in the vertebral body of the spine of a child was usually erroneously diagnosed as tuberculosis. Brackett realized that this was not

correct, and thought that the condition was osteochondritis. The condition in one of the patients presented here had been diagnosed a fracture. The child had fallen down a flight of stairs. A compression fracture of a single vertebral body of a child would be most uncommon and I recommended a biopsy.

Sir Thomas Fairbank reviewed the program for this meeting, and a few days ago I received a letter from him in which he stated that he was very much interested in the suggestion that eosinophilic granuloma might be the cause of vertebra plana. (I would like to make it clear that we are not by any means suggesting that it is the only cause of vertebra plana; but it is the only one that we know about.) Sir Thomas called my attention to, and sent me a reprint of, a lecture which he had delivered in October 1952 in which he quoted from a case of a girl, four years of age, reported by Snapper and described as multiple eosinophilic granuloma. In this patient, there was a collapse of the sixth thoracic vertebra. Sir Thomas Fairbank, who is certainly one of the senior "deans" of orthopaedic surgery, is remarkably alert. He expressed in his lecture the opinion, "Personally I feel that eventually vertebra plana will be proved to be one manifestation of granulomatosis and not a clinical entity".

In spite of the fact that in all of the cases which we have reported the only entity which was definitely demonstrated was eosinophilic granuloma, I am of the opinion that other granulomatous lesions may produce the same thing. One of the discussors reported a case of a single vertebral body undergoing destruction, and mentioned that it was a malignant lesion. He did not, however, state whether or not that vertebral body ever became the typical flat vertebra of vertebra plana. We have all seen sympathicoblastoma in children which destroyed one or more vertebral bodies, but I have not observed an instance in which it produced a typical vertebra plana. In reply to the criticism that two of these patients did not show complete flattening of the vertebral body with the appearance of a "coin on edge" as shown in the x-ray and as described by some of the early writers on the subject, we would remind you that these cases were diagnosed early and that treatment by x-ray therapy and support to the spine was begun in time to prevent the flattening of the vertebra.

In our Case 2, destruction by the lesion was extensive. The vertebral body was almost devoid of tissue and certainly had a cavity. The curette simply fell into the hollowed-out body of the vertebra. The tissue was very soft and yet tenacious. It was not easy to pull it loose from the bone to which it was attached. For this reason I have thought it rather unlikely that we could obtain good tissue material in such cases by means of needle biopsy. In one instance it was necessary to take hold of the tissue with the forceps and remove it with the dissecting scissors.

DISCUSSION

Delayed Union and Non-Union of Tibial Fractures

(*Continued from page 968*)

connective-tissue components in general and of osseous-tissue components in particular. Their studies have clearly shown that the connective tissues in the areas in which imperfect healing is taking place oftentimes, or perhaps consistently, display the morphological features of fibrinoid. This is an interesting observation, and the efforts of the authors to determine its significance are well justified. For the present, however, it may be necessary to adopt a conservative appraisal of the significance of the presence of fibrinoid. In the first place, fibrinoid is difficult to define exactly, and in the second place, the occurrence of fibrinoid in a wound which is not satisfactorily healing conceivably might be the result rather than the cause of imperfections in healing sequences.

This study by Dr. Urist and his associates is a significant one and one which has been thoughtfully planned and carefully executed. It is to be hoped that with the aid of improved methods and with proper application of the rapidly increasing knowledge of the composition and behavior of connective-tissue elements, it will become possible to describe the pathogenesis of delayed union and non-union in precise chemical and biological terms. The authors have made a significant contribution in this direction, but I am sure that they would be among the first to contend that there is much more to be learned about this troublesome clinical problem.

Dr. Urist (closing): We owe a debt of gratitude to Dr. Bennett for his work which called our attention to the phenomenon of fibrinoid degeneration. We are in agreement with Dr. Bennett's comment that fibrinoid may be a by-product of healing; our present view, however, is that, although there are many apparent clinical causes and combinations of causes, there is one mechanism common to all—fibrinoid degeneration of connective tissue in the interior of the callus. Some questions have been asked about the effect of a bone graft on healing of fractures. We like to think of it in terms of the function of a catalyst; the catalyst makes possible a chemical reaction, but it does not itself enter into the reaction.

EXPERIMENTS ON PAIN REFERRED FROM DEEP SOMATIC TISSUES *

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From the Departments of Anatomy and Neurology, School of Medicine, University of California, San Francisco

Pain provoked by the irritation of tissues deep to the skin has a characteristic quality and tends to be diffusely "referred". Unlike acute pain from the skin, it persists for a considerable period of time, is rather slowly transmitted to the consciousness, and is often associated with autonomic or other "reflex" concomitants, such as bradycardia, a fall in the blood pressure, nausea, and skeletal muscle spasm.

Although the radiating nature of deep pain has always been of theoretical and clinical interest, it has been experimentally investigated in muscle only since Lewis [6] and Kellgren [4] used the method of injecting hypertonic saline. Kellgren [5] mapped the segmental areas of deep pain and tenderness below the fourth cervical vertebra by systematically stimulating the "interspinous ligaments" of three subjects. His technique was used by Campbell and Parsons to produce referred pain from the upper cervical "somites". Inman and Saunders studied the relation of experimentally induced pain to clinical problems of deep pain and introduced the concept of "sclerotomes".

These studies have received only scanty critical consideration. It also still seems to be frequently taken for granted that the segmental distribution of deep pain follows the familiar dermatomes. Little attention, moreover, has been paid to the autonomic and affective concomitants which are characteristic of pain in deep tissue.

A systematic study of the patterns of pain which follow the stimulation of paravertebral ** and limb muscles was, therefore, carried out [8]. The number of subjects used was larger than that investigated in Kellgren's work, and the upper cervical segments were included. In addition, observations were made on such concomitant phenomena as the autonomic repercussions and the cutaneous sensory changes in the skin overlying areas of deep pain, and on the influence of somatic and sympathetic-nerve block.

METHOD

Subjects

The paravertebral muscles of the neck and back were systematically injected with a 6 per cent. saline solution at each intervertebral level from the atlanto-occipital area to the lower portion of the sacrum. Five subjects were used in the testing of each injection site. A total of 140 individual observations was made. The subjects were the authors approximately seventy-five medical students, and three laboratory assistants.

Procedure

The desired level for a particular injection site was first obtained by reference to adjacent bony landmarks and by palpation of the vertebral spinous processes. An intradermal wheal was raised, by the use of 1 per cent. procaine solution. This point was situated in the mid-line, midway between two adjacent spinous processes. The test injection of 0.5 to 1.0 milliliter of 6 per cent. saline solution was then made by means of a 2-inch 24-gauge needle. After the skin had been punctured, the needle was directed about 15 degrees toward either the right or the left. The depth of the insertion depended upon the adiposity of the subject, the essential requirement being the placement of the needle tip

* A contribution from the Biomechanics Group, sponsored by the Department of Orthopaedic Surgery and aided by a grant from the Advisory Committee on Artificial Limbs, National Research Council.

** By the term *paravertebral muscle* is meant the musculotendinous tissue immediately on either side of the mid-line of the spine.

Figs. 1-A through 1-D: Drawings show the patterns of referred pain after intervertebral injections of 6 per cent. saline solution. At each level, the areas of deep pain found in five subjects are superimposed. The levels included in this series are from the first through the eighth cervical.

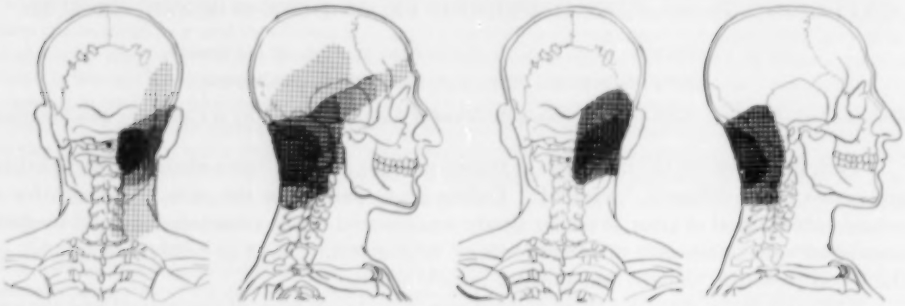

FIG. 1-A

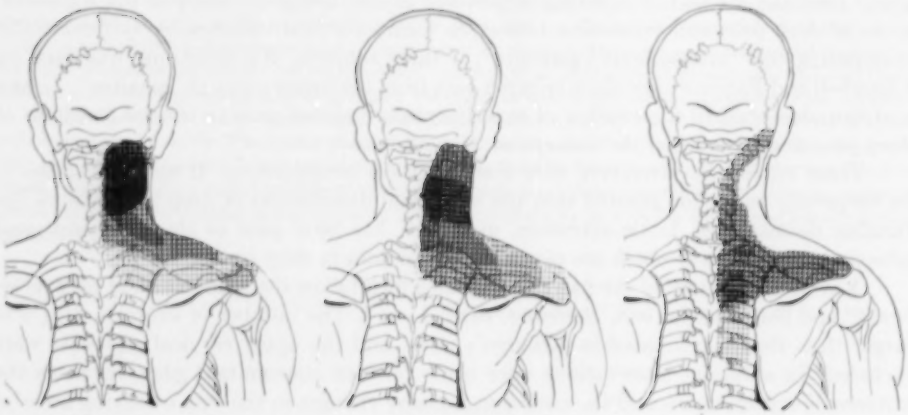

FIG. 1-B

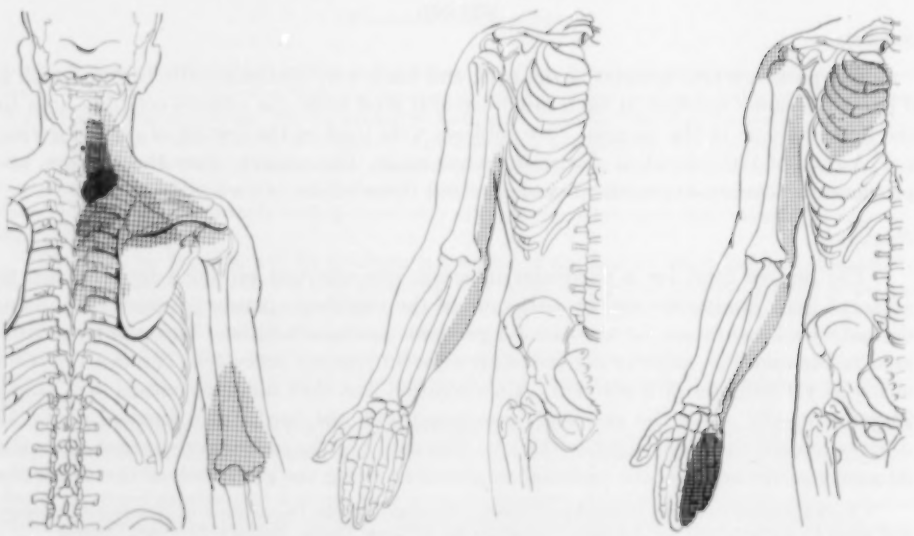

FIG. 1-C

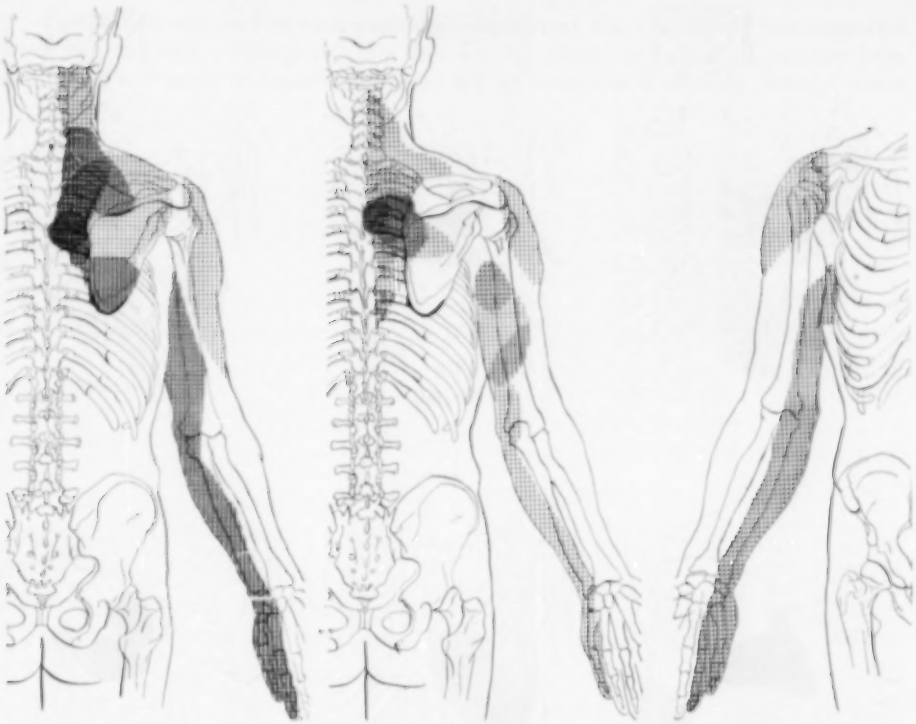

FIG. 1-D

in the musculotendinous interspinous tissues. A small lead pellet was taped to the overlying skin as a marker for roentgenographic confirmation of the precise level.

The subjects were briefed on the entire procedure and during the testing were given notice of each step in order to reduce apprehension. They were told that the pain, while likely to become quite severe, would fade rapidly and would disappear entirely in eight to

Figs. 2-A through 2-H: Drawings show the patterns of referred pain after intervertebral injections of 6 per cent. saline solution. At each level the areas of deep pain found in five subjects are superimposed. The levels included in this series are from the first through the twelfth thoracic.

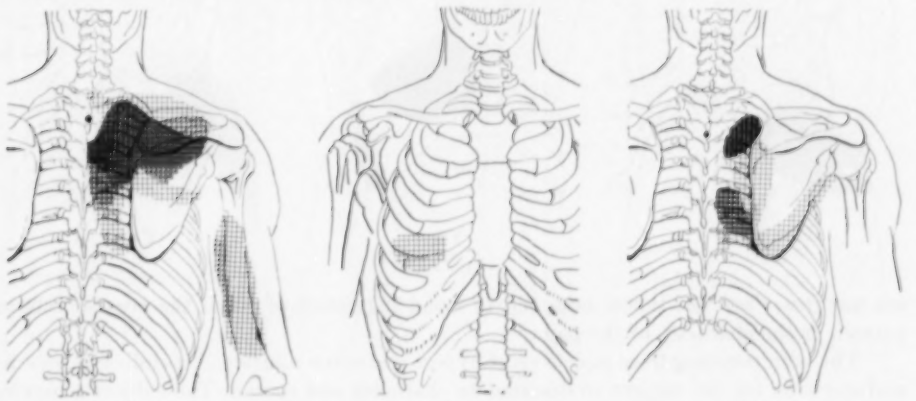

FIG. 2-A

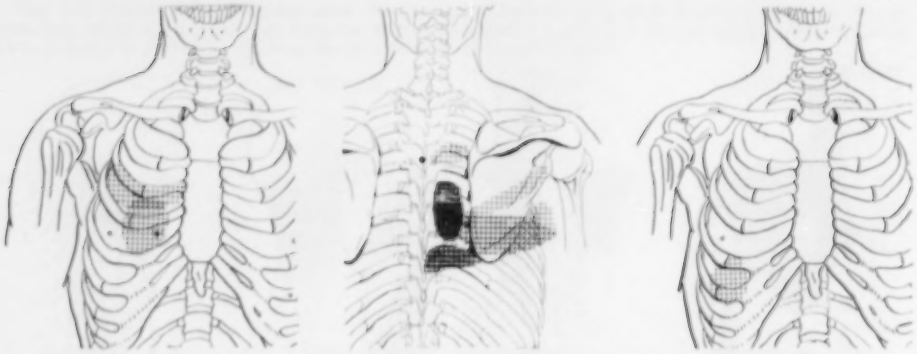

FIG. 2-B

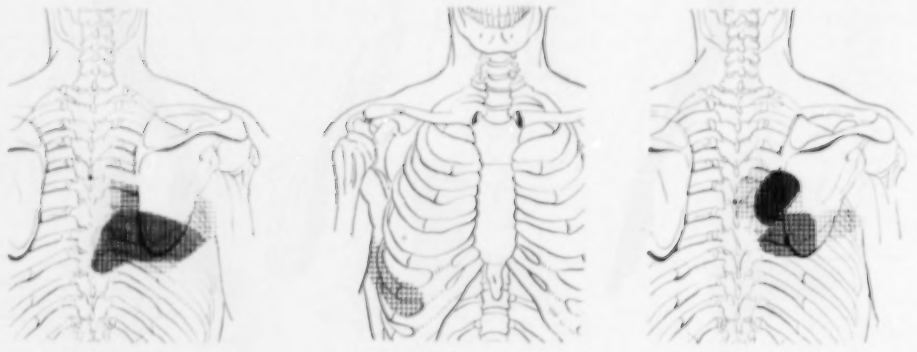

FIG. 2-C

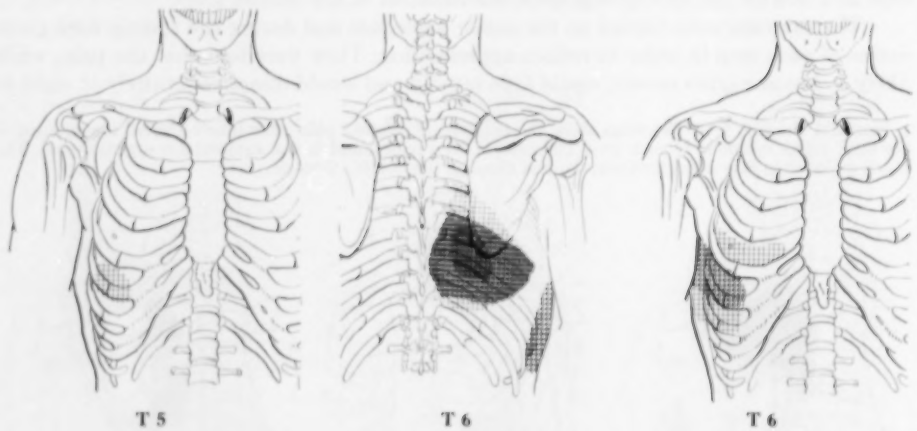

FIG. 2-D

ten minutes. Care was taken, however, to avoid suggestion of either the possible referral pattern or the character of the pain.

The pain resulting from injections of hypertonic saline solution is of sufficient severity and duration for the subject to describe its character and spread. The subject's running comments were recorded by one observer, while another sketched the location of the reported pain on a printed outline of the body and skeleton. The medical training of the subjects added to the reliability of recording.

The pattern obtained in each individual experiment was transferred to transparent paper with fine square rulings and was then cut out. With the individual patterns from each of the five subjects superimposed, gradations in density of shading resulted which

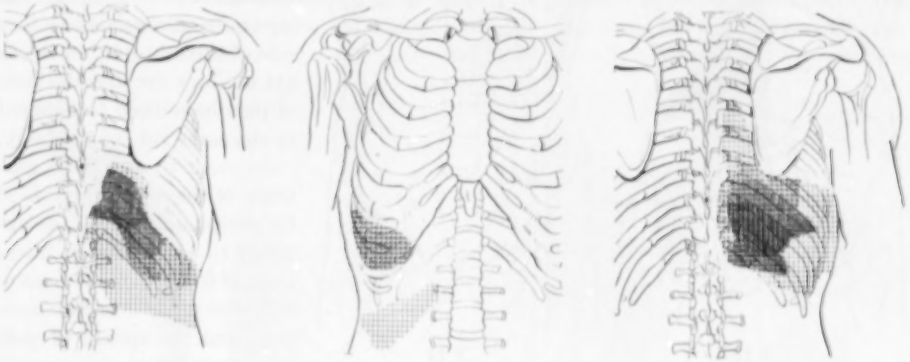

FIG. 2-E

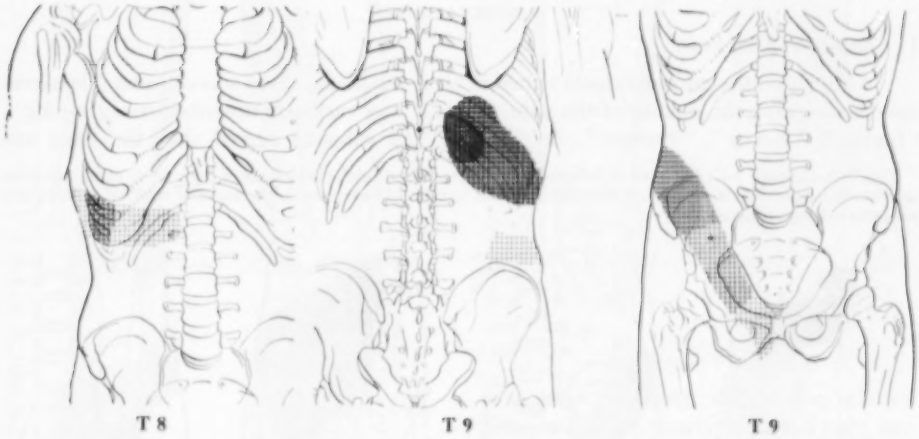

FIG. 2-F

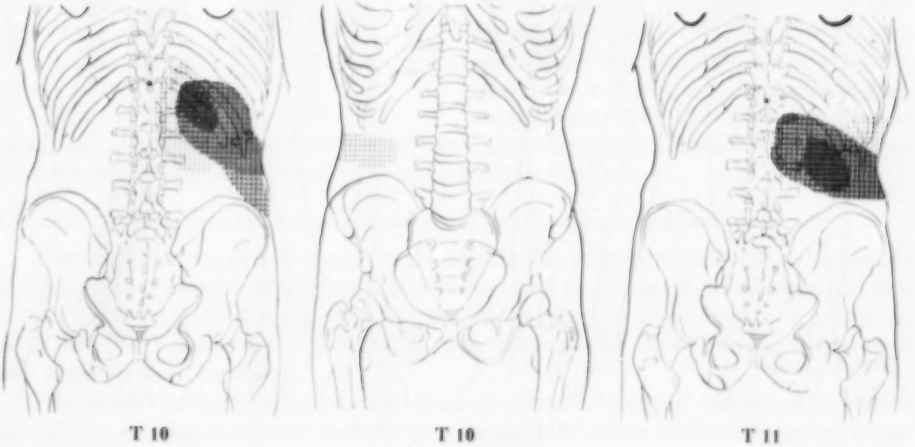

FIG. 2-G

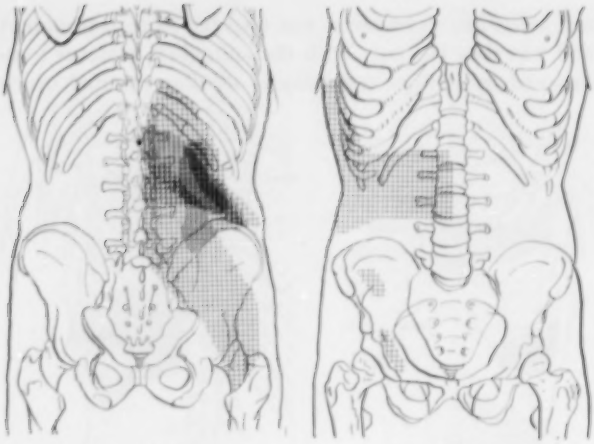

FIG. 2-H

gave the average distribution of deep pain for each segmental level (Figs. 1-A through 4-B). Although the injections were made to either side of the mid-line, on the final outlines the distributions of pain have been transposed to the same side of the body.

In order to study the patterns of deep pain activated by peripheral stimuli, as opposed to axial stimuli, injections of 6 per cent. saline solution were made into limb muscles, and the spread of pain was recorded in the manner described (Figs. 5-A–5-F).

OBSERVATIONS

1. *Character of the Pain*

Although different individuals varied in their reactions, there was considerable agreement concerning the quality of the pain. While it was variously described as "gripping", "boring", "heavy", "crampy", or "lumpy", all subjects agreed that the pain was

Figs. 3-A through 3-C: Patterns of referred pain after intervertebral injections of 6 per cent. saline solution are shown for the levels of the first through the fifth lumbar. At each level, the areas of referred pain in five subjects are superimposed.

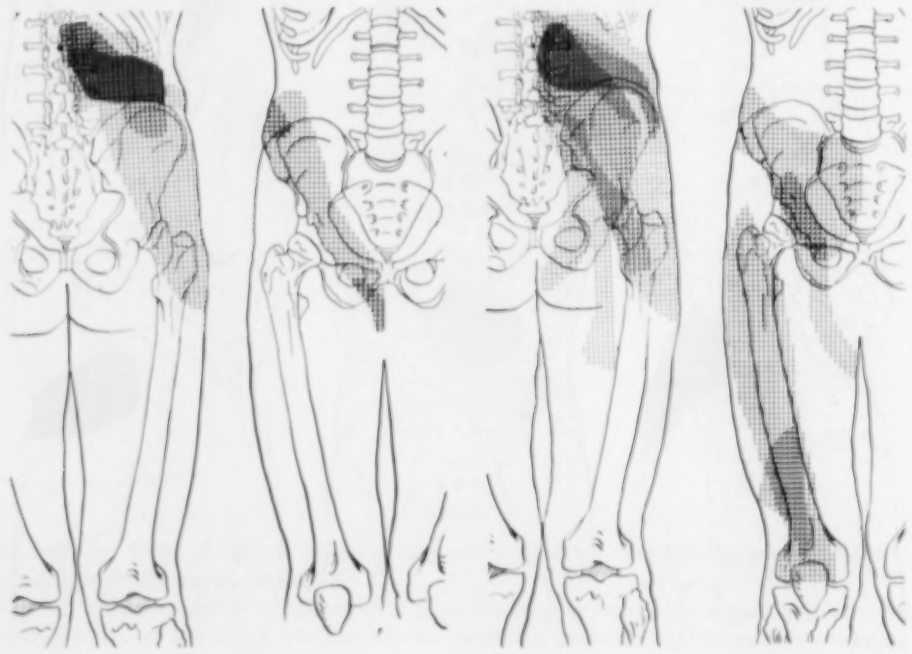

FIG. 3-A

"deep", and most of them used the word "aching". The word "area" did not seem appropriate for expressing the essentially three-dimensional character of the pain.

The intensity of the pain ranged from the absence of discomfort in two subjects to extreme pain, frequently accompanied by acutely unpleasant autonomic reactions. The amount of pain depended upon the amount of saline injected, but the autonomic concomitants did not seem to be proportional. There was usually a gradual increase of pain

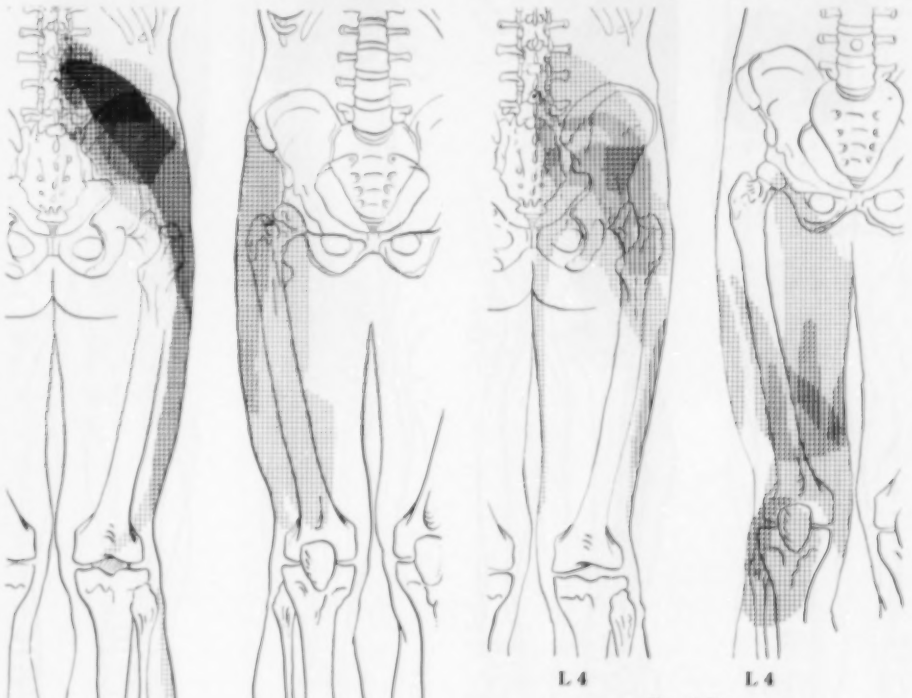

FIG. 3-B

to a peak intensity within one minute. First, a diffuse, poorly localized pain was felt in the vicinity of the injection. Even before attaining peak intensity, the pain spread from this area, occasionally in a continuous manner. More often, however, there was a discontinuous referral of pain to a distant area. The distant or referred pain frequently gained in intensity as the local pain continued to increase, and quite often the referred component persisted fully as long as the local pain.

2. *Distribution of Pain following Stimulation of the Paravertebral Muscles*

Figures 1-A through 4-B represent the distribution of pain following the stimulation of interspinous tissue innervated by the posterior rami of the spinal nerves from the first cervical level to the third sacral level. On the skeletal outlines a dot marks the site of the injection. The densest part of the overlay pattern represents the distribution of referred pain common to five subjects.

The factors influencing the extent of the area of referral were (1) individual variations and (2) the amount of irritant used. Greater amounts of saline tended to produce larger painful areas.

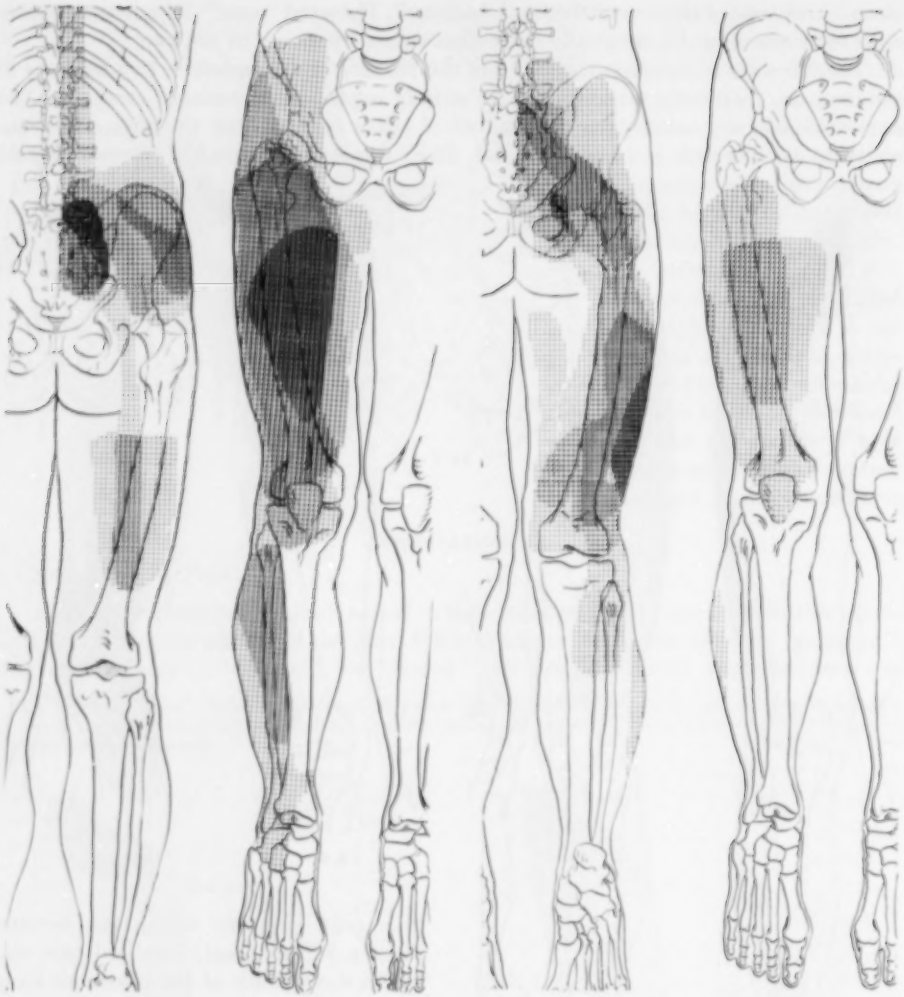

FIG. 3-C FIG. 4-A

Figs. 4-A and 4-B: Patterns of referred pain after intervertebral injections of 6 per cent. saline solution are shown for the levels of the first through the third sacral. At each level the areas of referred pain in five subjects are superimposed.

Stimulation of the first cervical level provoked pain in the occipital region. In one instance, pain was referred to the forehead (Fig. 1-A, *C1*). The posterior aspects of the neck and occipital region were affected by stimulation of the second, third, and fourth cervical levels. Referral into the shoulder was observed following stimulation as high as the third cervical level. There was a particularly marked overlap in the upper cervical region. This may possibly be accounted for by the fusion of the cervical and occipital segments which takes place during development. Thus, stimulation of the tissues derived from the third, fourth, and fifth cervical segments may give no separable distributions of pain.

Following stimulation of the sixth cervical segment, pain was referred into the arm and forearm in two of the five subjects. Stimulation of the seventh cervical segment provoked pain in the ulnar side of the arm and forearm. The same distribution was produced

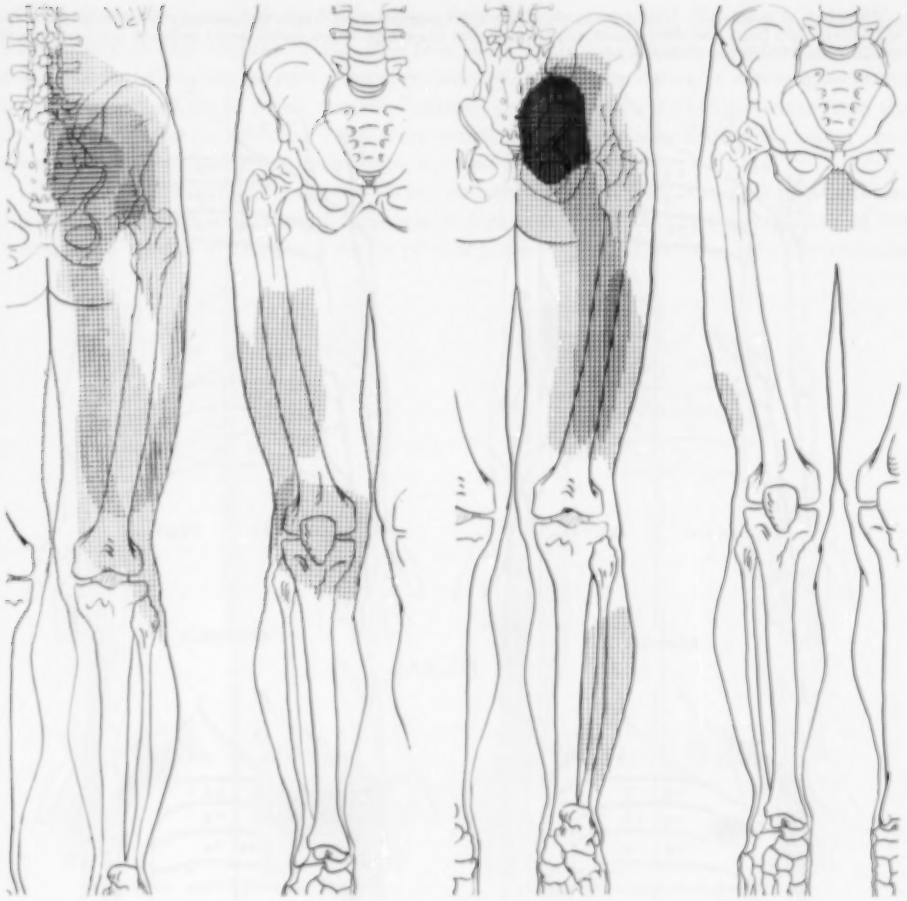

FIG. 4-B

at the eighth cervical segment. Referral to the radial side of the forearm and the hand occurred in none of the subjects. With stimulation of muscle supplied by the thoracic roots, pain was confined to the chest and abdomen, with the exception that stimulation at the twelfth thoracic segment gave referral into the hip region. Stimulation of muscles supplied by the lumbar and sacral nerves produced pain extending fairly uniformly into the buttock and thigh region. Pain from the third lumbar, fifth lumbar, and first sacral levels was referred into the calf of only three subjects. The foot was not a site of referred pain in any of the experiments. The areas of deep pain referral, especially in the extremities, are thus located differently from the conventional dermatomes and are far more overlapping.

3. *Distribution of Pain following Stimulation of Limb Muscles* *

To compare the segmental referral patterns following paravertebral (axial) irritation with those following peripheral irritation, a series of single peripheral muscles, which had given rise to referred pain in the paravertebral series, were injected with 6 per cent. saline solution (Figs. 5-A through 5-F). The muscles were: brachialis (fifth and sixth cervical

* Part of this work was submitted by Marion Cleeves (now Dr. Marion Cleeves Diamond) in partial fulfillment of the requirements for the Master of Arts degree, University of California.

Figs. 5-A through 5-F: After injections of the limb muscles with 6 per cent. saline solution (three or four subjects), deep pain was distributed as shown in the drawings. Cross-hatch areas indicate deep pain, while parallel lines indicate cutaneous hypo-algesia.

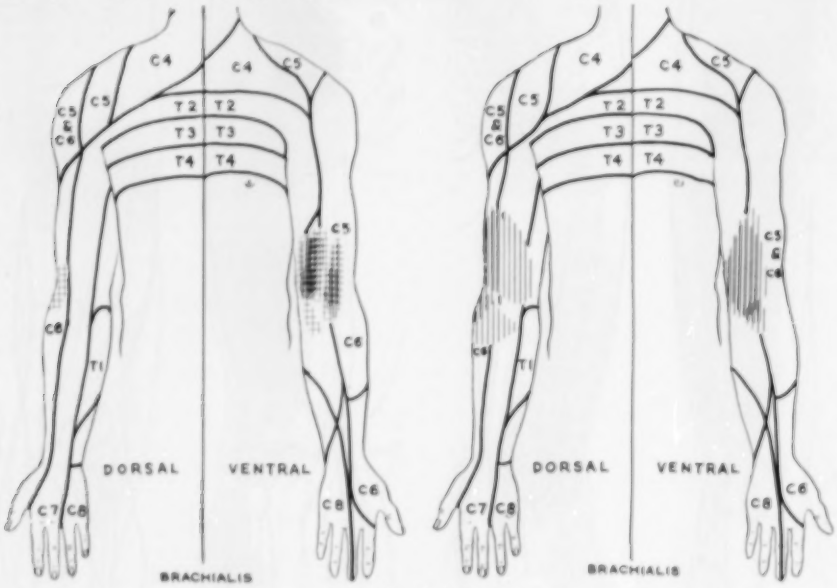

FIG. 5-A

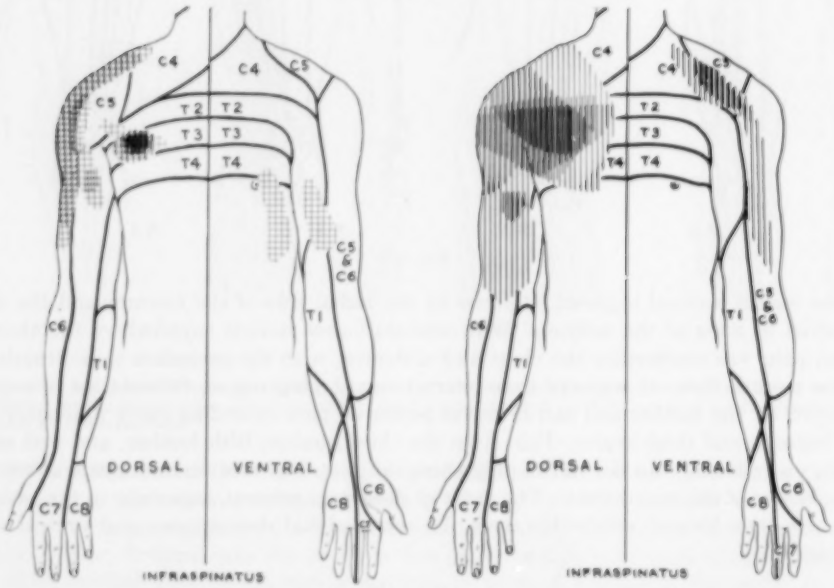

FIG. 5-B

levels), infraspinatus (fifth and sixth cervical levels), extensor digitorum communis (sixth, seventh, and eighth cervical levels), serratus anterior (fifth, sixth, and seventh cervical levels), flexor carpi ulnaris (eighth cervical and first thoracic levels), and pectoralis major (fifth, sixth, seventh, and eighth cervical levels)*. Three or four subjects were used for each muscle.

* Innervations after *Morris' Human Anatomy*. Ed. 11, p. 1152, 1953.

As it was in the series with injections of paravertebral muscle, the deep pain was felt immediately in the vicinity of the injection; and, within a minute, it spread along the muscle fibers. The area of pain, however, was neither confined to the whole muscle nor did it always occupy the whole muscle. Referred pain arose at variable distances from the injection site, and the affected areas were sometimes larger and sometimes smaller than the anatomical outline of the individual injected muscle.

Although it was never referred to the paravertebral muscles, the pain radiation on the whole coincided with the patterns which had been obtained from stimulation of the interspinous tissues of the same levels of innervation. With injections into the serratus

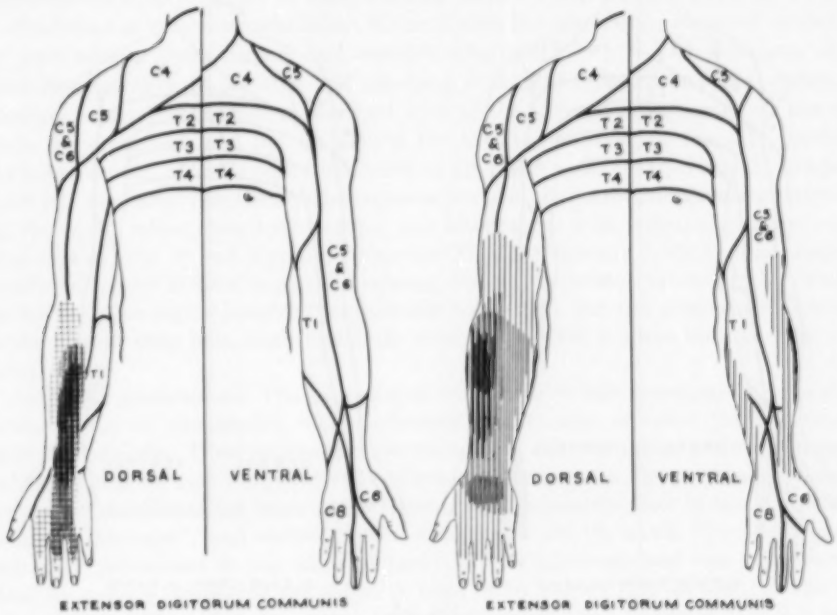

FIG. 5-C

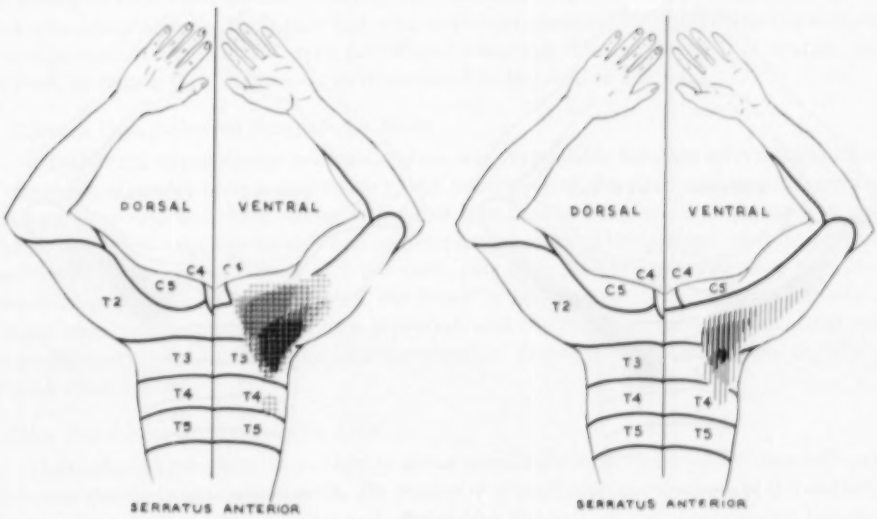

FIG. 5-D

anterior (fifth, sixth, and seventh cervical levels), the pain spread to the contiguous area underlying the second and third thoracic dermatomes, that is, the axilla and its surroundings (Fig. 5-D). On the other hand, there was also evidence that muscles innervated by the same roots of the brachial plexus referred pain to the same area. Thus, when saline solution was injected into the latissimus dorsi (sixth, seventh, and eighth cervical levels), the pain involved the sum of those areas which could be obtained individually from separate injections into the flexor carpi radialis longus (sixth cervical level), abductor pollicis longus (seventh cervical level), and first dorsal interosseus (eighth cervical level).

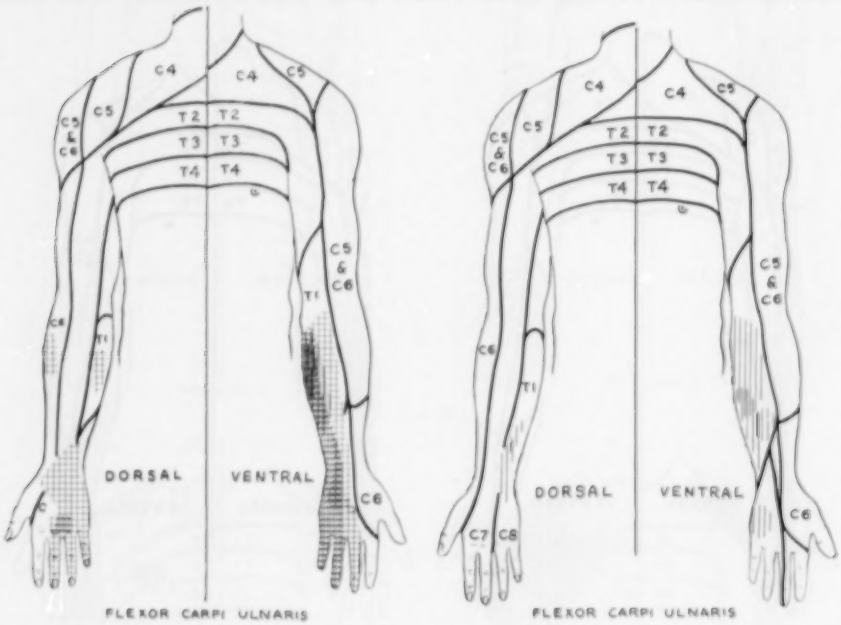

FIG. 5-E

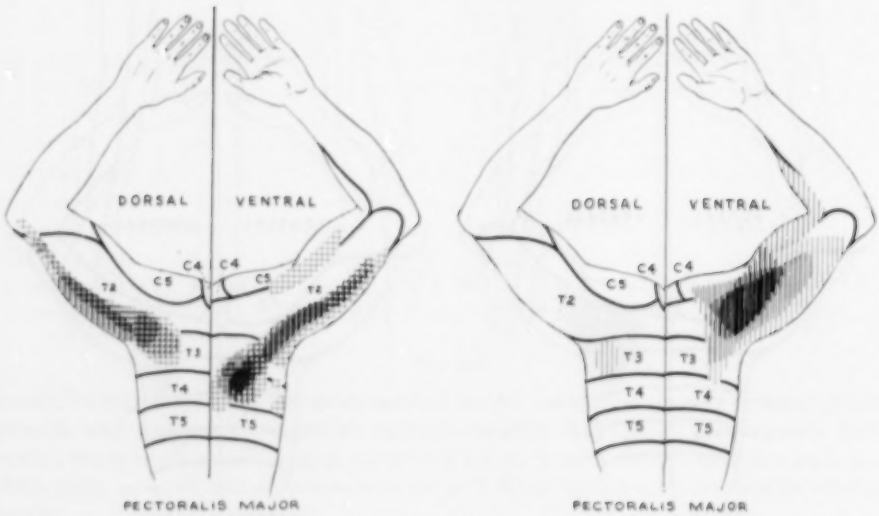

FIG. 5-F

4. *Concomitant Features*

Deep tenderness and muscle spasm: Deep tenderness was present in most cases. This was found uniformly in the regions of radiation, but only variably in isolated areas of referral. Tenderness could be elicited for as long as twenty-two hours following the injection. The area was always smaller than that of referred pain. The greatest discomfort upon deep pressure was felt in muscles which also exhibited spasm. These were often situated at some distance from the point of stimulation. For example, an injection at the level of the sixth cervical segment was fairly consistently accompanied by spasm of the supraspinatus, infraspinatus, or biceps. It will be noted that each of these muscles derives its motor-nerve supply, in part at least, from the sixth cervical segment of the spinal cord.

Alterations of cutaneous sensibility: Hyperalgesia has often been observed to accompany pain arising from visceral and somatic structures [2, 7, 10, 12]. The skin area of increased susceptibility to pricking and pinching is usually reported as lying within the dermatome which corresponds to the cord level of the affected deep tissues. In our own subjects hyperalgesia could not be elicited by pricking or brushing the skin overlying either referred pain, regional deep tenderness, or any other area. On the contrary, pinprick was not felt as clearly over the affected areas as it was in the surrounding regions. Hypo-algesia, therefore, rather than hyperalgesia, was often noted with injections both of interspinous tissues (Fig. 6) and peripheral muscles (Figs. 5-A through 5-F). The hypo-algesia was sufficiently well defined to permit mapping, but its evanescent nature precluded elaborate testing. The region involved was usually concentric, but not necessarily identical, with the area of deep pain, and frequently extended beyond it when limb muscles were injected.

Autonomic concomitants: The pain elicited from muscles was accompanied by a characteristic group of phenomena which indicated involvement of other than segmental somatic mechanisms. These autonomic reactions were most common with injections in the thoracic region, and comparatively rare with injections in the cervical and sacral regions. The manifestations were pallor, sweating, bradycardia, fall in blood pressure, subjective "faintness", and nausea, but vomiting was not observed. Syncope occurred in two early procedures in the series of paravertebral injections and was subsequently avoided by quickly depressing the subject's head or by having him lie down at the first sign of faintness. These features were not proportional to the severity of the pain or to the extent of radiation; on the contrary, they seemed to dominate the experience of subjects who complained of little pain but who were overwhelmed by this distressing complex of symptoms. Most common were pallor and sweating. The sweating was usually generalized; in only a few instances was it confined to the side of the pain.

5. *Referred Pain following Sympathetic Block*

Whether the sympathetic nervous system was responsible for pain referral was tested in one medical student. As a preliminary, the interspace of the sixth and seventh cervical vertebrae was injected three times with 6 per cent. saline solution, and the area of pain referral in the left arm was established in the usual manner. Then the left stellate ganglion was blocked with ten milliliters of 2 per cent. procaine. A Horner's syndrome and vasodilatation on the affected side proved the block to be effective. The segmental injection of 6 per cent. saline solution was now repeated, and the resulting pain was identical with the preliminary pain in intensity and distribution. If anything, it rose more rapidly to its peak than before.

6. *Pain Referred to an Anaesthetic Area*

That referred pain may be evoked in areas previously anaesthetized by regional nerve block was shown in one experiment. By means of a preliminary injection of 0.5 milliliter of 6 per cent. saline solution into and slightly to the left of the interspinous ligament

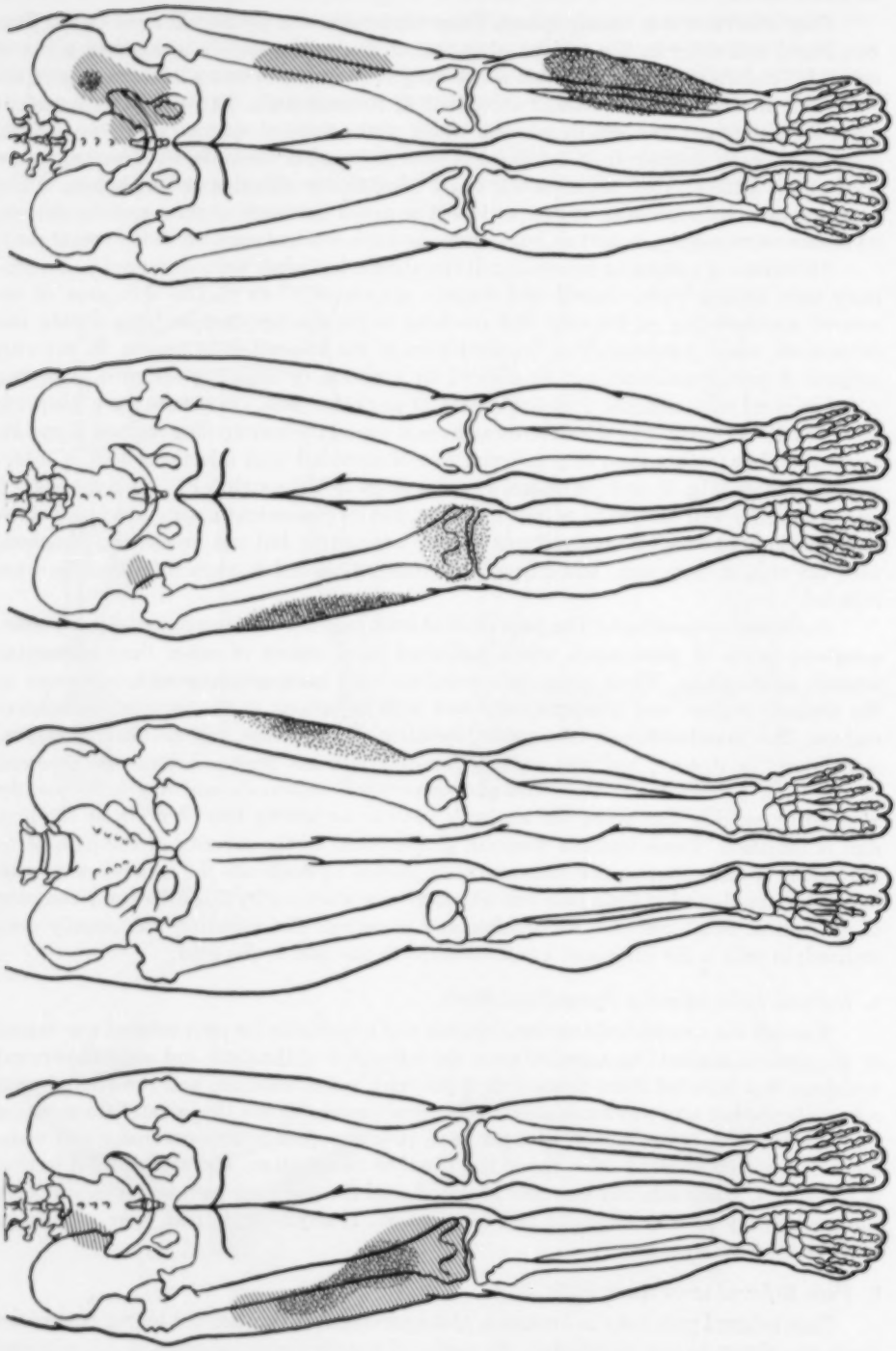

FIG. 6

Fig. 6: After intervertebral injections of the first through the third sacral levels with 6 per cent. saline solution (one subject each), deep pain was distributed as shown. Parallel lines indicate areas of deep pain; stippling denotes cutaneous hypo-algesia.

between the spinous processes of the sixth and seventh cervical vertebrae, pain was produced in the ulnar side of the left forearm. Thus, the level of injection for the particular distribution was established in this experimental subject (a medical student). Next, the left brachial plexus was blocked by infiltrating twenty-five milliliters of 2 per cent. procaine. Complete paralysis, with anaesthesia for all modalities including deep pain, was achieved for the entire left upper limb, and a left-sided Horner's syndrome gave proof of effective sympathetic block. Local injections of 0.4 milliliter of 6 per cent. saline solution into the left brachioradialis muscle and into the left thenar eminence failed to induce pain. The sensory and motor paralysis was complete for over thirty minutes.

Early in this period, a second interspinous injection of 0.5 milliliter of 6 per cent. saline solution was given at the identical site of the preliminary injection. Despite the regional anaesthesia of the arm, this second interspinous injection was followed by a dull, aching, deep pain in the ulnar side of the left forearm, only slightly less intense than the pain which had resulted from the preliminary injections in the non-anaesthetized limb.

DISCUSSION

Noxious stimulation of the back muscles at different levels provokes pain in distributions which vary but little from individual to individual. Although the overlap between successive levels exceeds even that seen in dermatomes, the regional patterns suggest a segmental organization. The muscles in which the referred pain is apparently felt all derive their approximate motor-nerve supply, and possibly their sensory-nerve supply, from the segment stimulated by the paravertebral injection. By no means, however, are all the muscles attributed to one segment affected.

Kellgren [6] stated that the pain was "fully segmental in distribution". However, he based his opinion on what appeared to him to be a stimulation of truly segmental structures,—namely, the interspinous ligaments. Sinclair and his associates [10] rightly pointed out the difficulty of selective injections into interspinous ligaments. It is indeed almost certain that paravertebral muscles, rather than ligaments, are being injected, and surface anatomy provides no certain way of verifying the precise segmental representation of these muscles. Kellgren's critics [10] maintained that the saline solution must spread through the tissues and stimulate sensory-nerve "trunks" therein. Whatever their size, sensory nerves or their endings are stimulated, and at each level of injection the afferent impulses enter the spinal cord *via* one, or possibly more than one, posterior division and dorsal root. The number of branches stimulated will be determined by the amount and the diffusion of the injected irritant. The volume injected accounts not only for the intensity of the ensuing pain but also for the extent of its referral. To avoid excessive spread and pain, the amount injected was in our experiments kept within the indicated limits. Whether or not the results obtained should be called truly segmental is, however, an academic question, since sharply delimited segments of sensory organization in the spinal cord are not likely to exist, especially not for deep tissues. The patterns of pain, therefore, may give as good an indication of this organization as one can expect.

Although similar methods of provoking pain were used in Kellgren's investigation and ours, his assessment of segments was based on deep tenderness, whereas our criterion was spontaneous, aching pain. In our experience, areas of tenderness showed no close correspondence to those of aching pain. Detailed comparisons of his patterns of pain with ours cannot, therefore, be made. The discrepancies, such as they are, pertain chiefly to the lower cervical and the sacral segments. Our patterns at these levels differ far more from the conventional dermatomes than Kellgren's do.

It must be emphasized that the spread of pain is felt three-dimensionally, although

only two of these dimensions can be indicated on surface outlines. Thus, in the trunk "areas" the pain may be partly felt within the body cavities and come close to sensations of visceral pain.

While there is a good deal of correspondence between the referred pain of disease and that of these experiments, our findings of associated cutaneous sensory changes differ from other experimental and clinical accounts, especially from the notion of "Head's zones". Hypo-algetic areas of skin, concentric with areas of deep pain, have to our knowledge not been reported except in the tables recently produced by Steinbrocker and his associates and in an article by Sturge, published seventy years ago. The latter author commented on the "numbness" and "heaviness" of the left arm during attacks of anginal pain. Yet the experience is a common accompaniment of any deep ache. In our subjects the hypo-algetic zones followed no clear-cut dermatomal patterns; their relation to the hitherto known segmental innervation of muscle, on the one hand, and that of the skin, on the other, remains somewhat obscure.

The discrepancy between our findings of hypo-algesia and the hyperalgesia almost uniformly reported in the literature is hard to explain. It is possible, however, that the observers' expectation, as well as semantics, may be responsible in so far as the term "numbness" is concerned. In nerve lesions producing both pain and numbness, cutaneous hypo-aesthesia and hyperalgesia of the same area are common. It is often difficult for the untrained patient to make this nice distinction. The over-all experience of unpleasantness may mask the actual reduction of sensory acuity. Nevertheless, it was the intensity of pinprick which our subjects unanimously declared to be reduced in the areas in question.

Regarding the injections of peripheral muscles, we cannot conclude with certainty that more than part of the "full segment" was as a rule activated, a point also made by Travell and Bigelow and by Steinbrocker and his associates.

After brachial plexus block, referred pain in the anaesthetic area was readily evoked by the appropriate axial injection. Thus, there is little reason to believe that peripheral-nerve function, including the axon reflex [11], played any part in this kind of referred pain. The central segmental organization, when adequately stimulated at the spinal level, is fully able to produce and to account for the projection of deep pain to the periphery. In other words, such stimulation is capable of lighting up the relevant area of the body scheme. Sympathetic denervation does not block this mechanism.

The interspinous injections showed that, with an approximately segmental referral of pain, multiple concomitants may be observed which are referable to disturbances within and beyond the various sectors of segmental organization. In the cutaneous sensory system we found hypo-algesia; in the motor system, muscle spasm; in the autonomic system, a wide range of cardiovascular, sudomotor, and gastro-intestinal effects. We are led to endorse Ruch's convergence-projection theory of referred pain and to regard this disturbance as a "central" phenomenon which consists of the setting up of an excitation at the spinal segmental level in the first place. With increasing intensity the excitation spreads beyond the spinal segment to result in a wider referral of pain and in autonomic and emotional disturbance.

SUMMARY

The patterns of deep somatic pain referral were studied with paravertebral injections of 6 per cent. saline solution from the occiput to the sacrum, five subjects being used for each intervertebral level. The distributions were found to approximate a segmental plan, although they overlapped considerably and differed in location from the conventional dermatomes. Pain could not be induced in the radial aspect of the upper limbs and in the feet. Injections into individual peripheral limb muscles showed less regularity in suggesting segmental patterns. As opposed to the hyperalgesia of "Head's zones", areas of hypo-algesia, usually in a concentric manner, were found to overlie the locations of in-

duced deep pain. Sympathetic and somatic (plexus) blocks did not interfere with the segmental referred pain produced by this method, thus suggesting a primarily spinal integrative mechanism. The character of the pain and its autonomic concomitants are described, and the theoretical implications are discussed.

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FRACTURES OF THE CARPAL NAVICULAR (SCAPHOID)

A Report of 436 Cases *

BY MARCUS J. STEWART†, M.D., MEMPHIS, TENNESSEE

Diagnostic errors are more common in fractures of the carpal navicular (scaphoid) than in fractures of any other bone of the body. Without exception, such a fracture is produced by a force transmitted through the proximal palmar surface of the hand.

There are four types of carpal navicular fractures, although any combination of these types may be observed:

1. Fracture of the tubercle;
2. Fracture of the distal third;
3. Fracture of the middle third or waist. The majority are of this type (80.45 per cent. in this series);
4. Fracture of the proximal third.

Fractures through the proximal third and often those through the waist of the carpal navicular may deprive the proximal fragment of its blood supply. Obletz and Halbstein, reporting on an anatomical study of 297 fractures of the carpal navicular, found that fracture through the waist will deprive the proximal third of all its blood supply in 13 per cent. of the cases. Compere and Banks observed that fracture through the waist results in necrosis of the proximal fragment in approximately one third of all cases. Further, they point out that the incidence of avascular necrosis of the carpal navicular is second only to that of the head of the femur. Healing must take place by direct trabeculation or interfragmental osteogenesis. Normally, the blood is supplied by two primary arteries, one entering through the tuberosity, the other through the waist.

In fresh fractures which are properly reduced, there is no argument against immediate, adequate, and continuous immobilization. The most favorable position for immobilization, however, is the subject of much controversy. Berlin's excellent study by dissection and analysis of sixty wrists reveals that at no point in the arc of motion are the fragments uniformly approximated. Viewed from the dorsal aspect during flexion, the fragments are increasingly separated, while on the palmar side they are approximated. In extension, the reverse is true. He concludes that the position of choice is approximately 45 degrees of extension of the wrist with moderate radial deviation.

Ritter believed that wide abduction and complete extension of the thumb are necessary in order to secure firm locking of the fragments. Cleveland, however, observed that the thumb may be immobilized in any one of various positions, with equally good results. Friedenberg concluded from his experiments that the position of the thumb did not influence the position of the fragments. Apparently, the position of the thumb is not of major importance.

REPORT OF SERIES

While with the United States Army Medical Corps in the European Theater of Operations from September 1942 to September 1945, the author observed 436 fractures of the carpal navicular. Of these, eleven were incomplete fractures in the distal third; all healed without delay. Three were bipartite scaphoids with associated sprain. The other 422 cases are the subject of this review. The majority of the cases, 323, were fresh or acute injuries which were diagnosed immediately or within one month. The remaining ninety-nine were

* Read at the Annual Meeting of the American Medical Association, Orthopaedic Section, Chicago, Illinois, June 12, 1952.

† Formerly Lieutenant Colonel, Medical Corps, Army of the United States.

FIG. 1

Shows type of plaster cast used for immobilization of the carpal navicular. Note "grasping pose" and range of motion of the metacarpophalangeal joints.

old fractures, the average period of time which had elapsed before the diagnoses were made being thirty-eight weeks.

Conservative Treatment

For immobilization, we selected a position of maximum relaxation of the carpus, a "grasping pose" (Fig. 1). The wrist was placed in extension of approximately 30 degrees with mid-ulnar and radial deviation. The first metacarpal was abducted, while the metacarpophalangeal and interphalangeal joints of the thumb were flexed toward the palm. A circular plaster cast, skin-tight except for one layer of stockinette, was applied from one inch below the elbow to the metacarpophalangeal joints and the base of the thumbnail on the dorsal aspect and to the proximal crease on the palmar side. The hand could thus be passed through the sleeve of the average shirt or coat. Movement of the interphalangeal joint of the thumb was allowed, provided the plaster did not weaken and permit motion of the metacarpophalangeal joint. Since the middle fibers of the abductor of the thumb are attached to the tubercle of the navicular, motion of the metacarpophalangeal joint would move the fracture. The thumb was relaxed and the metacarpophalangeal joints of the fingers were completely free. The patients were able to carry on an active program of play or work, and they were encouraged to participate in rope-climbing, tumbling, chinning exercises, bag-punching, and even baseball.

The practice of having the patients clench the fist during the period the plaster is setting was avoided. In closing the fist, the flexor muscles recede proximally, reducing the circumference of the wrist. If the plaster hardens in this position, the patient will have considerable difficulty in extending the fingers and opening the hand.

It was our policy to change the cast and to re-examine the navicular by roentgenograms at the end of every four to six weeks. When the plaster was removed, the patient was instructed not to move the thumb or wrist. When necessary, immobilization was re-instituted immediately after the roentgenographic examination. The routine studies included a true anteroposterior view, a lateral view, and two oblique views, one in pronation of 45 degrees and one in supination of 45 degrees (Figs. 2-A through 2-D).

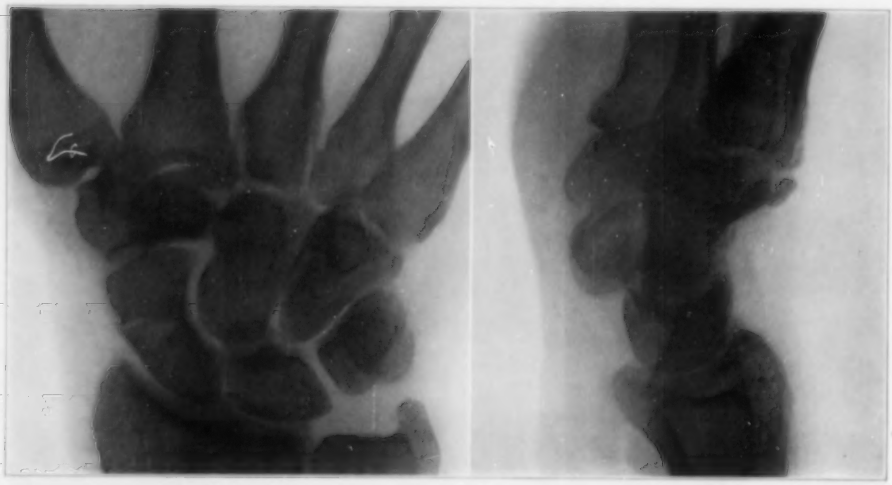

FIG. 2-A FIG. 2-B

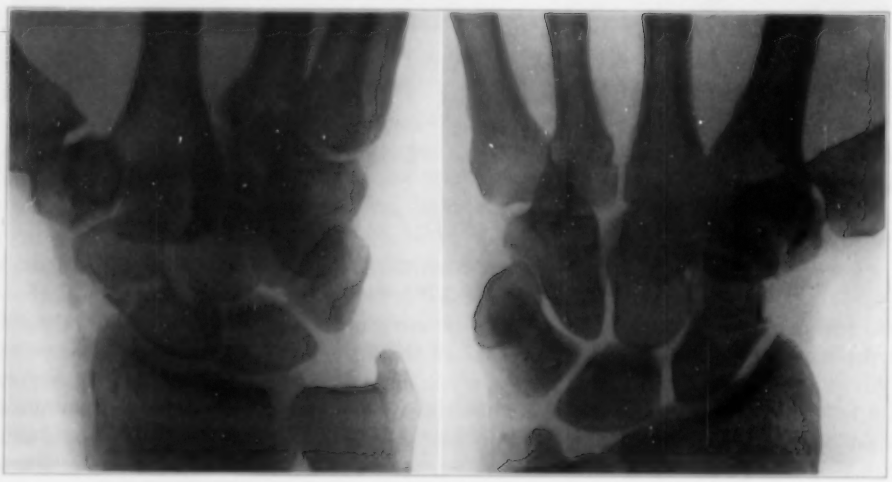

FIG. 2-C FIG. 2-D

Routine roentgenographic views for examining the carpal navicular.
Fig. 2-A: Anteroposterior view. Fig. 2-B: Lateral view.
Fig. 2-C: Oblique view in pronation of 45 degrees.
Fig. 2-D: Oblique view in supination of 45 degrees.

Because of policies on hospitalization in the European Theater of Operations, some of the patients were returned to the United States and we were unable to follow them to the conclusion of treatment.

FRESH FRACTURES

Results of Conservative Treatment

Of the 323 patients with fresh fractures, 320 were treated only by immobilization in plaster. Of this group, 258 patients obtained solid bony union with restoration of full function in the wrist and hand. They had an excellent range of painless motion, no point tenderness, a normal grip, and normal strength in the wrist. Sixty-two patients were transferred to other hospitals or to the United States. At the time of transfer, forty-five of the sixty-two patients were progressing satisfactorily and union was expected; three

TABLE I

FACTORS INFLUENCING HEALING IN 258 FRESH FRACTURES

Treatment by Immobilization in Plaster (Average of Twelve Weeks)

Factors	No. of Cases	Average Duration of Immobilization (*Weeks*)
Location of Fracture		
Distal third	44	8
Waist	207	12
Proximal third	7	23
Accuracy of Reduction		
Excellent	120	10
Good	129	14
Fair	9	16
Cystic Changes		
Mild to marked	41	16
Sclerosis		
At fracture site	10	21
Proximal fragment	12	21

patients had definite signs of persistent non-union, while fourteen had been treated too recently to permit conclusions. Thus, it may be considered that 303 patients (approximately 95 per cent.) of the 320 treated by plaster immobilization obtained excellent or good results.

Operative Treatment

Three of the 323 patients were treated by early excision of the proximal fragment; all obtained good results.

Factors Influencing Healing

Location of the fracture: Fractures in the different locations of the carpal navicular should be considered separately, just as though separate bones in the different parts of the

FIG. 3-A FIG. 3-B

Fig. 3-A: Roentgenogram of the carpal navicular, showing fracture through the waist and sclerosis developing in the proximal fragment, despite early and adequate immobilization. This fracture required thirty weeks of immobilization in plaster before union and revascularization.

Fig. 3-B: The result was excellent.

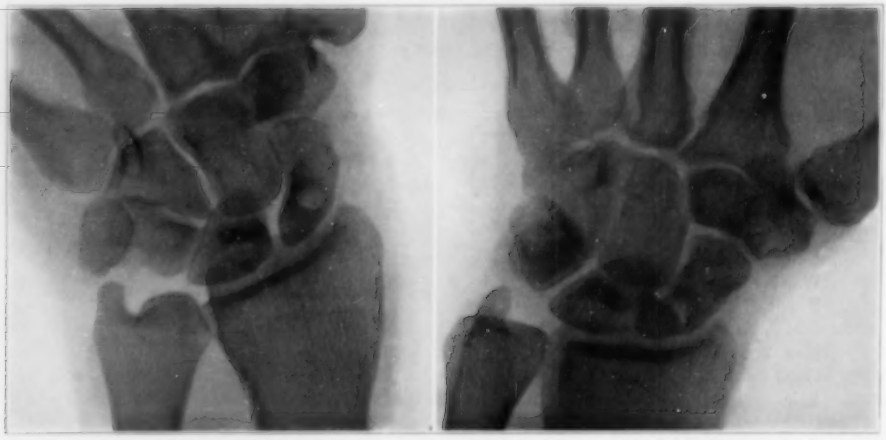

FIG. 4-A

FIG. 4-B

Fig. 4-A: Roentgenogram of a carpal navicular, showing a fracture which was not diagnosed for ten weeks. Note the cystic changes at the fracture site.

Fig. 4-B: After immobilization for five weeks.

Fig. 4-C: After twenty-two weeks of immobilization in plaster, the union was solid and the result was excellent.

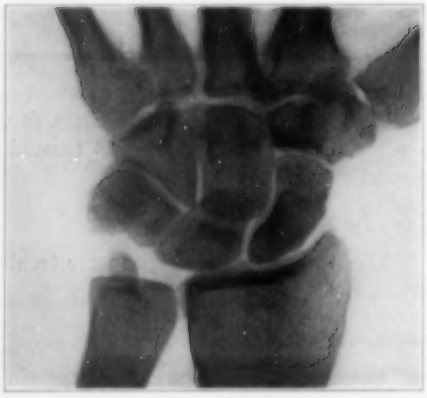

FIG. 4-C

body were involved. Of the 258 patients who obtained bony union under conservative treatment, forty-four (17 per cent.) had fractures of the distal third of the navicular. They required immobilization in plaster for five to twenty weeks, the average period being eight weeks. In 207 patients (80 per cent.), the fracture involved the waist or middle third. These fractures were immobilized in plaster for three to thirty-five weeks, or an average of twelve weeks. In only seven patients (3 per cent.) was the fracture in the proximal third. This group required from twelve to thirty-two weeks of immobilization, or an average of twenty-three weeks. The average period of immobilization for the entire group of 258 patients was twelve weeks (Table I).

The reconditioning period necessary after removal of the plaster was encouragingly short. The average time required for complete recovery of function was only 3.5 weeks. Activity of the fingers while in plaster maintains a good tissue turgor, stimulates the blood supply, and keeps the tendons freely movable.

Reduction: The accuracy of reduction is of paramount importance. Of the 258 patients, nine had a fair reduction; they spent an average of sixteen weeks in plaster. In 129 patients, good reduction was obtained, requiring fourteen weeks in plaster. The remaining 120 patients had anatomical reduction; these were immobilized for an average of ten weeks (Table I).

Vascular changes: In forty-one patients, mild to marked vacuolation or cystic changes were apparent at the site of fracture. An average of sixteen weeks in plaster was necessary for the group. Despite early diagnosis and adequate immobilization, avascular sclerosis developed in twenty-two (8.5 per cent.) of the 258 patients who obtained bony union and excellent results.

In ten patients, increased density, or sclerosis, was exhibited at the site of fracture. They were treated for eleven to thirty-five weeks in plaster, the average period being

TABLE II

FACTORS INFLUENCING HEALING IN 51 OLD FRACTURES

Treatment by Immobilization in Plaster (Average of Twenty Weeks)

Factors	No. of Cases	Average Duration of Immobilization (*Weeks*)
Location of Fracture		
Distal third	2	15.0
Waist	43	19.5
Proximal third	6	24.0
Accuracy of Reduction		
Excellent	9	10.9
Good	38	22.9
Fair to poor	4	23.1
Cystic Changes		
Mild to marked	42	19.3
Sclerosis		
At fracture site	9*	21.4

* Six of these patients showed arthritic changes but all had full range of motion and no pain or weakness.

twenty-one weeks. Twelve patients with avascularity of the proximal fragment spent an average of twenty-one weeks in plaster (Figs. 3-A and 3-B). In such cases, there is always the possibility that degenerative arthritis may develop later. Before leaving the hospital, however, all of the twelve patients were able to negotiate an obstacle course and participate in vigorous sports, and all returned to full duty with normal function of the hand and wrist.

OLD FRACTURES

The operative treatment of fractures of the carpal navicular includes bone-grafting, multiple drilling, excision of one or both fragments, excision of the proximal row, styloidectomy, arthrodesis of the wrist, pan-navicular arthrodesis, and now prosthetic substitution. Comparatively few of our patients were operated upon, first, because of foreign-theater policy and, second, because our results were surprisingly good following prolonged immobilization.

Results of Conservative Treatment

Of the ninety-nine patients with old fractures, ninety were treated by immobilization only. Fifty-one of these patients were returned to full duty; all had obtained solid bony union, as shown by roentgenograms, and all had an excellent range of motion in the wrist and hand, without tenderness and with normal grip and strength. Thirty-nine patients were returned to the United States or to other hospitals before conclusion of treatment. In fifteen of these patients, healing of the fracture was progressing satisfactorily at the time of transfer; twenty-one patients were transferred too early to permit the formulation of a definite evaluation of results; and in three patients the immobilization failed to result in union. Of ninety cases, union was complete in fifty-one (56.6 per cent.). Therefore, there was solid bony union or reasonable expectation of union in sixty-six patients (73.3 per cent.).

Factors Influencing Healing

The fifty-one old fractures which united following immobilization were reviewed with respect to their location and its influence upon the period of healing (Table II).

Two fractures involved the distal third. They were not diagnosed for sixteen and

thirty-four weeks, respectively. Immobilization in plaster was maintained for twenty-two weeks and eight weeks, an average of fifteen weeks.

Forty-three of the fractures were through the waist. They were not diagnosed for four to eighty-two weeks, an average of twenty-two weeks. Immobilization in plaster was maintained for six to fifty-nine weeks, an average of nineteen and a half weeks.

Six fractures of the proximal third were not diagnosed for ten to fifty-six weeks, the average period being twenty-three weeks. A period of twelve to sixty weeks of immobiliza-

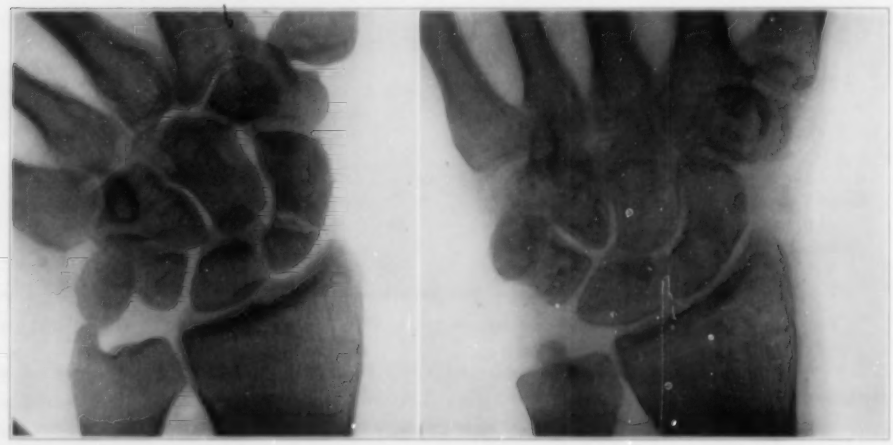

FIG. 5-A

FIG. 5-B

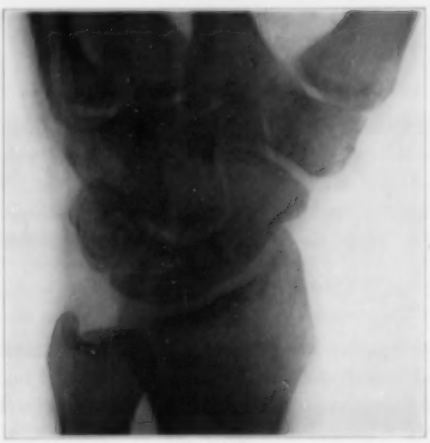

FIG. 5-C

Fig. 5-A: Roentgenogram of a fracture of the carpal navicular which remained undiagnosed for fifty-six weeks and which required twelve weeks' treatment in plaster.

Fig. 5-B: After immobilization for four weeks.

Fig. 5-C: The fracture union was solid, but there was mild osteoporosis.

tion in plaster was necessary, an average of twenty-four weeks.

Collectively, the fifty-one fractures were immobilized for an average period of twenty weeks. In contrast, an average period of twelve weeks of immobilization was required for fresh fractures. Thus, an average of eight additional weeks in plaster was made necessary by the delay in diagnosis.

The presence or development of cystic changes or sclerosis does not preclude the use of prolonged immobilization. The sclerotic area in many of the fractures with these changes looked worse after four to six weeks in plaster but gradually improved as immobilization was continued (Figs. 4-A through 5-C). The freedom and activity of the fingers and metacarpophalangeal joints contributed materially to the success of the treatment.

Results of Operative Treatment

The remaining nine patients were treated by surgery: five by autogenous bone grafts, two by excision of the proximal fragment, and two by multiple drilling.

In one of the patients treated by bone grafts, the graft was resorbed and the fracture failed to unite; the patient was transferred to the United States. Another had marked

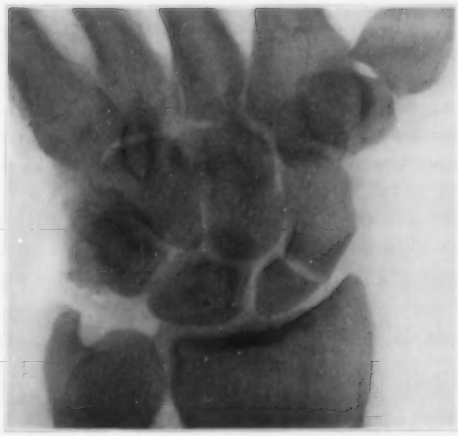

FIG. 6-A

FIG. 6-B

FIG. 6-C

FIG. 7

Fig. 6-A: Roentgenogram of a fracture of the carpal navicular which was not diagnosed for six weeks.

Fig. 6-B: After immobilization for twenty-five weeks, there was still no evidence of progress toward union. An inlay type of cancellous-bone grafting was done. Postoperative immobilization was for eight weeks, and four weeks were required for reconditioning.

Fig. 6-C: Three months after operation the patient returned to full duty as a truck driver.

Fig. 7: Roentgenogram of a fractured carpal navicular with marked displacement of a small proximal fragment. This was not diagnosed for forty weeks. After excision of the fragment and eight weeks of postoperative reconditioning, the patient returned to full duty.

stiffness with 50 per cent. disability of the wrist following operation; he was returned to limited duty. The remaining three patients returned to full field duty. Upon review of the roentgenograms and in the light of our present knowledge, there is every reason to believe that at least three of these fractures would have healed just as rapidly by immobilization alone.

Figure 6-A shows a fracture which was not diagnosed for six weeks and was immobilized for six months without improvement (Fig. 6-B). Eight weeks after excision of the fibrocartilage at the fracture site and an inlay bone graft, union was solid (Fig. 6-C). The patient returned to duty as a truck driver. This is the ideal indication for grafting,—that is, when viable fragments fail to show progress toward union after six months of immobilization.

Of two patients treated by excision, one had a fracture through the middle third of the navicular. The diagnosis was not made for twenty-four weeks; a mild sclerosis was

apparent at the fracture site and a moderate sclerosis in the proximal fragment. After ten weeks of postoperative treatment, the patient returned to limited duty, with pain and weakness in the wrist and an estimated 40 per cent. disability.

The second patient who was treated by excision had a fracture of the proximal third of the navicular which had remained undiagnosed for forty weeks (Fig. 7). The proximal fragment was markedly displaced. The fragment was excised and, after eight weeks of postoperative reconditioning, he was returned to full duty as a paratrooper.

One of two patients whose fractures were treated by drilling obtained union within six weeks, but a period of seven weeks of reconditioning was required before he returned to full field duty. The other had no signs of union eighteen weeks after the drilling and was returned to the United States.

CONCLUSIONS

Every severe sprain or injury in the region of the carpal navicular should be considered a fracture until proved otherwise.

The results in these cases substantiate good orthopaedic teaching that, if a fracture of the carpal navicular is accurately reduced and adequately immobilized for a sufficient time, solid bony union may be expected.

Failure to diagnose, to reduce, and to immobilize these fractures properly is directly responsible for delayed union or non-union.

In delayed treatment, the presence of vacuolation or cystic change is not considered discouraging. When the fracture has been properly immobilized, the healing which takes place in the cystic area will include the fracture line.

If the proximal fragment is viable, sclerosis at the site of fracture is no contra-indication to prolonged immobilization. As a rule, after two or three months of uninterrupted immobilization, decalcification of the sclerosis will be observed, signs of union will follow, and ultimately solid bony union will take place.

In adequately immobilized fresh fractures, the development of avascular sclerosis in the proximal fragment is no contra-indication to continued non-operative treatment. In the majority of cases, the fracture will unite and the proximal fragment will be revascularized. The wrist must be protected until revascularization is complete.

Rarely will normal function of the wrist be obtained following excision. Bone-grafting or drilling will not, except in an occasional case, offer any better prospect of union, nor will they, as a rule, reduce the average period of disability.

In the occasional fracture with excessive displacement of the proximal third, early excision of the proximal fragment is recommended, unless accurate reduction can be obtained by manipulation.

The type of plaster cast described ensures adequate immobilization of the navicular and allows the patient excellent use of the hand.

Immobilization may be prolonged for a year or more if daily exercise and activity of the fingers are systematically practised.

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PIGMENTED VILLONODULAR SYNOVITIS OF THE HIP JOINT

A Case Report*†

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It is the authors' purpose to present a case of pigmented villonodular synovitis of the hip joint, with retroperitoneal extension simulating an abdominal tumor. Various terms had been used to describe the xanthomatous lesions of synovial membrane, bursae, and tendon sheaths until Jaffe, Lichtenstein, and Sutro in 1941 originated the term "pigmented villonodular synovitis". A review of the literature in 1951[6] showed that approximately eighty-one joint xanthomata had been reported. In most of these cases either the knee joint or the smaller joints of the extremities were involved. Cases with involvement of the hip joint are rare and only the cases reported by Smith-Petersen[2] in 1944 and by Clark[3] in 1951 are similar to that here presented.

CASE REPORT

A white man, twenty-seven years old, was admitted to the Hospital on January 30, 1953, with a diagnosis of left femoral hernia. He had first noted a gradually enlarging mass in the left femoral triangle two weeks before his admission. Two days after the onset, there was a concurrent enlargement of a mass in the left lower abdominal quadrant. No other symptoms were reported.

The history revealed a report of sanatorium treatment for active pulmonary tuberculosis from June 1948 to June 1950. After rest and repeated pneumoperitonea, administered through the left lower abdominal quadrant, had failed to control the disease in the right lung, a three-stage right thoracoplasty had been performed. Recent recheck studies had failed to show any activity. The patient had maintained good nutrition and had remained asymptomatic.

Physical examination showed a normal temperature, pulse, and respirations. There was a well healed eight-rib thoracoplasty on the right and normal breath sounds were heard over the rest of the lung fields. In the abdomen a non-tender, smooth, fluid mass filled the entire left lower quadrant, and a fluid wave extended through a like mass which filled the left femoral triangle (Figs. 1-A and 1-B). The presumptive diagnosis was a left psoas abscess. Complete blood count, urinalysis, sedimentation rate, and serological findings were normal. Aspiration of the femoral mass yielded 180 cubic centimeters of viscous serosanguineous fluid. Papanicolaou smears were negative on the sediment after centrifuging of this fluid. The fluid was found to be sterile upon bacteriological studies.

Roentgenographic studies of the chest showed an effective right eight-rib thoracoplasty and were otherwise normal. X-ray examination of the abdomen showed a mild bulge in the left psoas shadow and a soft-tissue mass overlying the wing of the left ilium. The thoracic and lumbar portions of the spine were normal upon roentgenographic examination, but areas of rarefaction were noted in the left acetabular rim and in the head of the femur (Fig. 2). Intravenous and retrograde pyelograms showed the left ureter to be deviated to the mid-line from the level of the fourth lumbar vertebra to the third sacral segment (Fig. 3-A). A barium enema showed the sigmoid colon to be displaced medially (Fig. 3-B).

Preoperatively two diagnoses were considered: (1) a quiescent psoas abscess and (2) a traumatic cyst of the abdominal wall due to the repeated pneumoperitonea administered in 1948.

On February 10, 1953, an exploration was performed through a long oblique left inguinal incision. After the transversalis fascia had been divided, a large cystic mass, covered by attenuated psoas muscle, was found. The mass was U-shaped. The anterior component communicated at the femoral ring with a posterior cyst which extended inside the psoas. During excision, the cyst was opened and approximately 1,000 cubic centimeters of viscous serosanguineous fluid exuded. The cyst lining was xanthomatous and contained, in addition to the viscous fluid, masses of greenish-yellow nodular tissue apparently undergoing degeneration. The cyst was followed to the left hip joint inside the psoas. It communicated with the joint;

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† The statements and conclusions published by the authors are a result of their own study and are not to be construed as reflecting the policy of the United States Navy or a part thereof.

FIG. 1

The tumor is outlined by skin marking. (Official United States Navy photograph.)

and, at the acetabular rim, small, hard nodules were removed. The cyst was removed together with most of the psoas. Sections of the acetabular rim were removed. The patient had an uneventful postoperative course.

On March 11, 1953, an arthrotomy of the left hip joint was performed. Upon incision of the hip-joint capsule, it was apparent that there was marked proliferation of the synovial membrane, with formation of villonodular masses. Many of these were detached from the main portion of the membrane and showed the disorganization and color changes of necrosis and degeneration. The capsular incision was enlarged and the ligamentum teres was severed, so that the hip could be dislocated. A large area of the acetabulum was found to be denuded of cartilage, apparently because of an overgrowth of diseased synovial tissue with resultant erosion (Fig. 4). The area normally occupied by cartilage was filled with a hypertrophic villonodular type of reddish tissue flecked with deep yellow. In the region of the intertrochanteric line of the femur, a defect was found, approximately 0.5 by 1 centimeter, which was filled with a yellowish-brown, fatty material. A similar area was found in the head of the femur, where there was actual invasion of bone with a punched-out area. This space was filled with hypertrophic yellowish-brown tissue. Sections from each of these various areas were examined and were later reported by the pathologist as being identical in character.

FIG. 2

The preoperative roentgenogram of the left hip joint showed a cystic lesion in the femoral neck, as well as cystic changes in the acetabular floor. (Official United States Navy photograph.)

All possible diseased synovial membrane was excised and the isolated lesions in the head of the femur, in the intertrochanteric re-

FIG. 3-A

FIG. 3-B

Fig. 3-A: Retrograde pyelogram, showing the deviation of the left ureter toward the mid-line. (Official United States Navy photograph.)
Fig. 3-B: Barium-enema study, showing medial displacement of the sigmoid colon by the abdominal mass. (Official United States Navy photograph.)

FIG. 4

The hip joint exposed, showing head and neck, each with a cystic lesion. The acetabulum can be seen at the left; the trochanter (hidden) is at the right. A punched-out area filled with yellow soft tissue may be seen in the region of the intertrochanteric line. This corresponds to the cystic area seen in the roentgenograms. In the depths, the acetabular cartilage is obscured by hypertrophic soft tissue, deep red in color and streaked throughout with yellow. (Official United States Navy photograph.)

gion of the neck, and in the base of the acetabulum were curetted, so that smooth, bleeding bone remained exposed. During the postoperative phase, balanced skeletal traction was maintained and healing occurred promptly. Active and passive motion was begun on April 3, and the patient was discharged from the Hospital on crutches on April 17, 1953. He was followed as an out-patient, and full weight bearing was permitted in August 1953.

The patient was again examined on June 1, 1954, at which time he was walking without any appreciable limp. He stated that he occasionally experienced very slight discomfort in the region of the left hip, but this has not been sufficient for him to visit a physician or to require medication and it has not interfered with his normal activities as a college student. Objective examination revealed that there was a flexion contracture of about 10 degrees in the hip, with a range of flexion from 170 to 40 degrees. Adduction was 0 to 40 degrees, external rotation 0 to 50 degrees, abduction 0 to 40 degrees, and internal rotation 0 to 40 degrees. The Trendelenburg sign was negative. The musculature of the thigh was well developed and compared favorably with that of the opposite side. Roentgenograms of the hip revealed the continued presence of a cystic lesion

Fig. 5: Photomicrograph (× 110) of the cyst wall, showing cleftlike spaces, foam cells, and pigmented macrophages. (Official United States Navy photograph.)

Fig. 6: Photomicrograph (× 220) of tissue from the acetabular rim, showing spicules of bone adjacent to tissue with cellular characteristics similar to those seen in Fig. 5. (Official United States Navy photograph.)

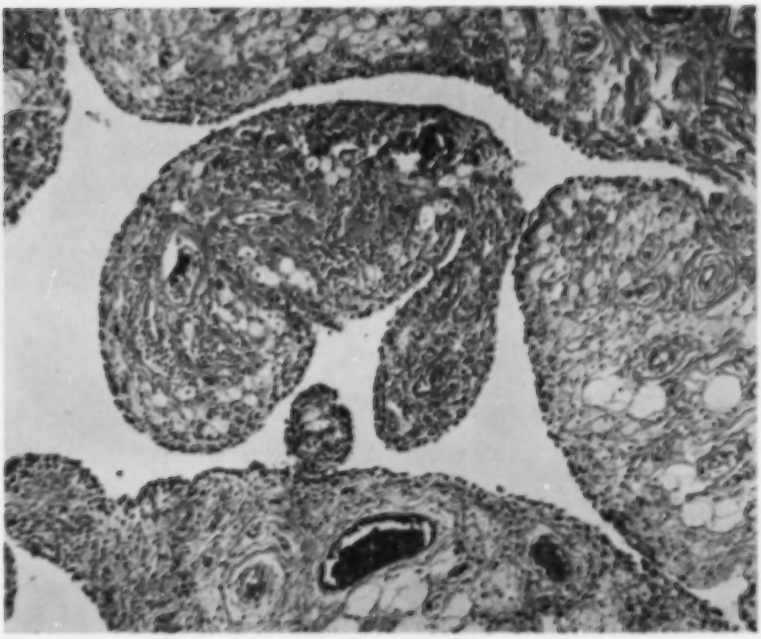

FIG. 5

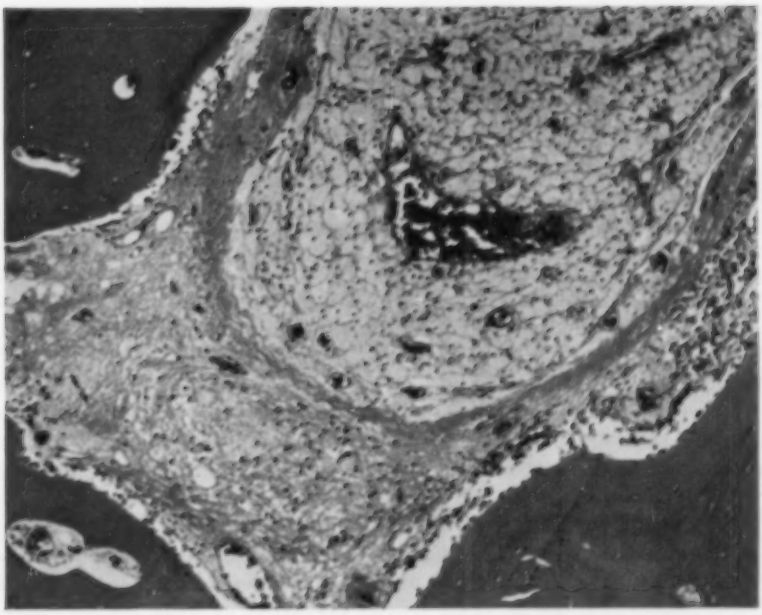

FIG. 6

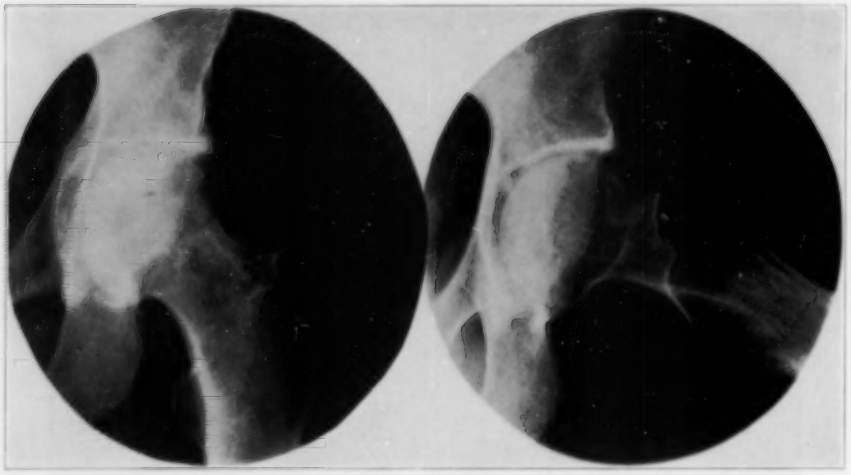

FIG. 7

Roentgenograms made fifteen months after arthrotomy. The cystic area in the femoral neck remains visible. Cystic changes in the acetabulum appear to have decreased. (Official United States Navy photograph.)

in the femoral neck, as well as some evidence of cystic changes in the floor of the acetabulum and in the inferior medial portion of the femoral head (Fig. 7).

The tissue removed at surgery was described by Commander James A. Turner, Medical Corps, United States Navy, Naval Medical School, Bethesda, Maryland, as follows:

"The retroperitoneal cyst wall shows a cavity lined by flattened synovia which is thrown into villous-like projections. The stroma consists of granulation tissue infiltrated by lymphocytes, lipoid-laden macrophages, and occasional multinucleated giant cells. Scattered macrophages containing granular brown pigment which gives a positive stain for iron are present. Sections of the hard villous nodules at the acetabular rim contain similar tissue without the cystic component. In addition, there are irregular cleft-like spaces lined by oval and flattened cells resembling synovial cells. Sections through the rim of acetabulum contain bone covered by articular cartilage. Within the bone, there is tissue similar to that described above replacing bone trabeculae. There is moderate resorption of bone as evidenced by osteoclasts grouped about the trabeculae." (Figs. 5 and 6.)

The pathological diagnosis was:

1. Pigmented villonodular synovitis, left hip joint;
2. Pigmented villonodular synovitis with cystic degeneration, retroperitoneal.

DISCUSSION

Previous authors[1,5] have attempted to classify pigmented villonodular synovitis as a synovial lesion constituting an intermediate group between lesions which are clearly inflammatory and those which are definite neoplasms. They state that trauma is usually linked with the onset. In neither the authors' case nor the similar case of Smith-Petersen's[2] was trauma reported. No consistent etiological factor has been found. The pathological findings are not entirely compatible with infection, trauma, hemorrhage, or neoplasm; and at present the lesion must remain classified between inflammation and neoplasm.

A search of the literature has failed to reveal a retroperitoneal extension of the lesion such as is reported here. This rare lesion must be considered in the differential diagnosis of tumors of the lower abdomen. Cases have been reported with involvement of the bursae which surround the hip joint. Weisser and Robinson reported an instance of involvement of the iliopectineal bursa. Such lesions occurring in large bursae often have a connection with the joint, but this may be difficult to demonstrate.

The case reported by Smith-Petersen[2] showed local involvement of the hip joint with areas of rarefaction in the head of the femur and the rim of the acetabulum. This was reported as a concurrent arthritic change, but in the authors' case it was believed to be a part of the entire process of pigmented villonodular synovitis.

The case reported by Clark[3] presented similar changes in the hip, particularly cystic changes in the femoral head and acetabulum. Pain was a feature in Clark's case. This feature was notably absent in the authors' case.

Greenfield and Wallace state that their experience with five cases indicates that roentgen therapy is the treatment of choice after exploratory arthrotomy and biopsy of pigmented villonodular synovitis. Most authors, however, feel that complete synovectomy with excision of all existing lesions is the treatment of choice, and that recurrence can be treated by roentgen therapy.

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DISCUSSION

Prognostic Implications of Electromyography

(Continued from page 911)

a very important one. If this could be done, it would greatly simplify treatment. Clinical evaluations have their limitations. Various methods of electrical analysis likewise have had their limitations. On the surface of things, it seemed that when electromyography was introduced, it would be the answer that we had sought, but it has not been so easy. The interpretation of electromyographic recordings has been difficult and confusing. It is in the clarification of these interpretations that Dr. Buchthal has worked so diligently, and we are receiving the benefit of his explorations.

In general, electromyography has been of greater value as a research tool than for practical considerations; but as interpretations have become more effective and dependable, the electromyogram has become more and more useful in clinical medicine. It is, for example, of great assistance in differentiating certain types of muscle disease.

Dr. Buchthal and his group have worked in a particularly difficult area. The electrical manifestations in poliomyelitis are especially complex and their interpretation is particularly difficult. In this group of patients, Dr. Buchthal and Dr. Madsen have been able to prognosticate very accurately, but their evaluations do not represent a simple process. It involves multiple needle electrodes; it involves considerable sampling of the muscle, because in poliomyelitis, of course, the effect of the disease is spotty; and it involves detailed scanning and study of the records. While it is not a simple procedure, Dr. Buchthal and Dr. Madsen have shown that, if it is done well, it is quite effective.

I hope that Dr. Buchthal and his associates will continue their explorations in this field. I hope, too, that simpler techniques may be evolved. Many things which appear in electrical recordings are still not well understood, but this study has been most stimulating and is entering the field of practical value in prognostic interpretation in the disease, thanks to Dr. Buchthal and his group. I cannot pay too much tribute to their detailed and accurate work. Finally, I would like to thank Dr. Buchthal for coming all this way to address us in such a masterful fashion in our language, not his.

(Continued on page 1030)

GIANT-CELL TUMOR OF THE HEAD OF THE HUMERUS

With a Case Report

BY FREDERICK E. STIEPAN, M.D., LEVITTOWN, PENNSYLVANIA

The malignant potentialities of certain of the giant-cell tumors have been demonstrated by many authors, and it is now recognized that giant-cell tumors are not universally benign, as was formerly believed. It is not generally known, however, that giant-cell tumors of the head of the humerus, which amount to about 6 per cent. of the total of all giant-cell tumors, carry a surprisingly poor prognosis. A discussion of these tumors will therefore be presented, with a report of a case of giant-cell tumor of the proximal portion of the humerus treated by primary resection and insertion of an acrylic prosthesis.

CASE REPORT

The patient, a normal, well developed, forty-year-old white male, had no symptoms referable to his left shoulder until May 1951, when severe pain developed in this shoulder which was diagnosed by his physician as "acute bursitis". He was treated by the usual methods and very shortly recovered. No radiation was given, and no roentgenograms were made.

He had no subsequent discomfort in this shoulder until December 1952. At this time, an aching pain developed which he ascribed to a return of his "bursitis". On January 12, 1953, he injured his left shoulder when he accidentally fell. Roentgenograms showed a large cystic type of radiolucent tumor involving the head of the left humerus (Fig. 1). The bony wall of the tumor was fractured. Except for pain in the region of the fracture, findings at physical examination were normal. The patient's maternal grandmother had died at the age of seventy-eight of "cancer" (site unknown). His past history was otherwise negative.

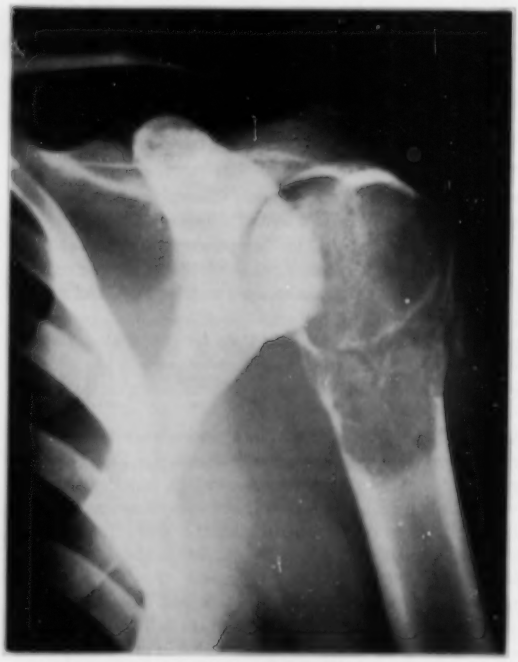

FIG. 1

Roentgenogram made at the time of the patient's original injury. The pathological fracture is clearly visible in the region of the greater tuberosity.

A biopsy of the tumor was performed on January 25, 1953, by Dr. Samuel J. Lloyd, Trenton, New Jersey. The tissue was studied microscopically by Dr. Thomas K. Rathmell, pathologist at Mercer Hospital, Trenton. It showed a fairly well vascularized stroma of connective tissue in which were noted a number of spindle cells, loosely arranged, as well as foci of hemosiderin pigment and a number of giant cells. For the most part, these giant cells appeared intimately associated with collagenous reticulum. Their nuclei appeared open and vesicular. In some portions of the tumor, the fibrous tissue showed a whorled pattern and some eosinophilic nucleoli. Occasional atypical mitoses were noted (Fig. 2).

On the basis of the classification of Jaffe and his associates, this tumor was classified Grade 2 (recurrence probable, possibly becoming malignant eventually). It was apparent that the size of the tumor precluded adequate removal by curettage and that roentgen therapy was attended by the danger of later radiation sarcoma. For this reason, total resection was planned with insertion of an acrylic prosthesis. A slide of the specimen and the roentgenograms were sent to Dr. Henry L.

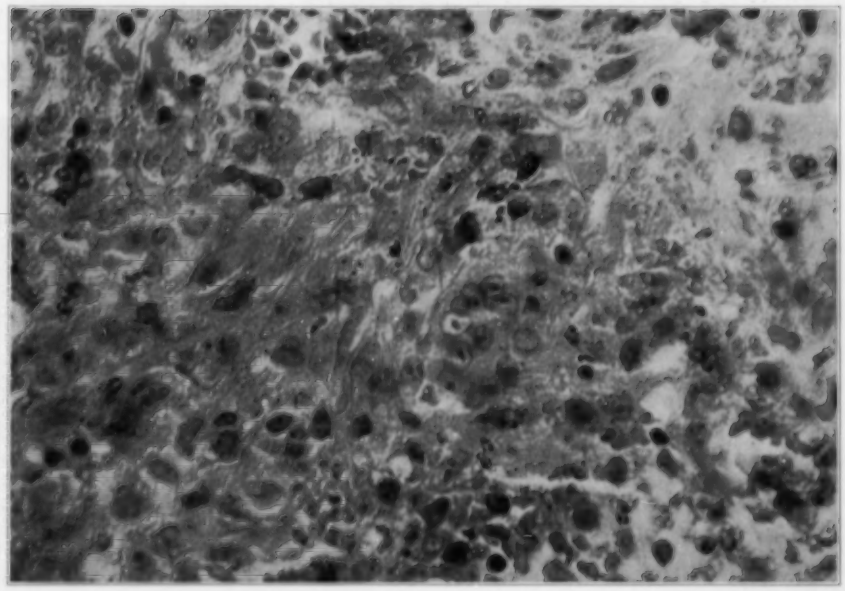

FIG. 2

Photomicrograph (× 110) of the original biopsy specimen.

Jaffe, who concurred in the diagnosis and in the plan to resect this tumor. Dr. John Royal Moore, after study of the patient, the slide, and the roentgenograms, also agreed with the proposed therapy.

A complete bone survey, chest roentgenograms, intravenous pyelogram, complete blood counts, urinalysis, and the Wassermann test gave normal findings.

Serum calcium	8.0 milligrams per 100 cubic centimeters
Serum phosphorus	5.5 milligrams per 100 cubic centimeters
Alkaline phosphatase	9.8 Bodansky units
Acid phosphatase	0.9 units *
Total proteins	7.25 grams per 100 cubic centimeters of serum.

The ratio of albumin to globulin was 4.3 to 2.95.

The sedimentation rate (modified Cutler method) was 14 millimeters per hour.

Operation was performed on February 20, 1953, through an incision which began at the lower border of the deltoid muscle, paralleling the anterior border of the deltoid to the clavicle, continuing along the lateral portion of the clavicle, across the acromion to the middle of the spine of the scapula. The deltoid muscle was released from its origin. The rotator cuff was detached, a generous attachment to the humerus being left. The tendon of the pectoralis major had to be severed. As the proximal portion of the humerus was exposed, the periosteum was found to be deficient over the site of the previous biopsy and in the region of the fracture. A section, ten centimeters long, of the proximal part of the humerus was removed. An acrylic prosthesis of the same length was then inserted (Fig. 3). The prosthesis used was a modification of that originally designed by Richard, Judet, and René. An attempt was made to reattach the rotator cuff through holes drilled in the prosthesis. (It was found that a larger opening through the prosthesis would have been desirable for reattaching the rotator cuff. MacAusland reattaches the rotator cuff by screws and washers in a concavity along the lateral head of his prosthesis.) Closure was then made. At the conclusion of the operation, the patient's arm was placed in a 50-degree abduction splint. His postoperative course was uneventful, and he was discharged from the Hospital on February 27.

The patient has been examined under fluoroscopy on two occasions and it appeared that the position of the prosthesis in the shaft of the humerus had been firmly maintained. However, to guard against swiveling, a diamond-shaped bar would probably have been desirable.

Pathological findings: The resected specimen (Fig. 5) consisted of the head and the proximal portion of the neck of the left humerus, having an over-all measurement of 9.5 by 6 by 6 centimeters. The head had a diameter of 4.7 centimeters. On the lateral aspect, in the region of the greater tuberosity, there was an area

* Method of Shinowara, Jones, and Reinhart.

of yellowish-white soft tissue intermixed with blood clot. In the inferior portion along the shaft, there was a scar containing clotted blood, marking the site of the previous biopsy. The head of the humerus at its junction with the shaft was expanded and was covered by a thin shell of bone which fluctuated upon palpation. On cross-section, the tumor showed a yellowish necrotic center, surrounded by bright red hemorrhagic tissue,

FIG. 3

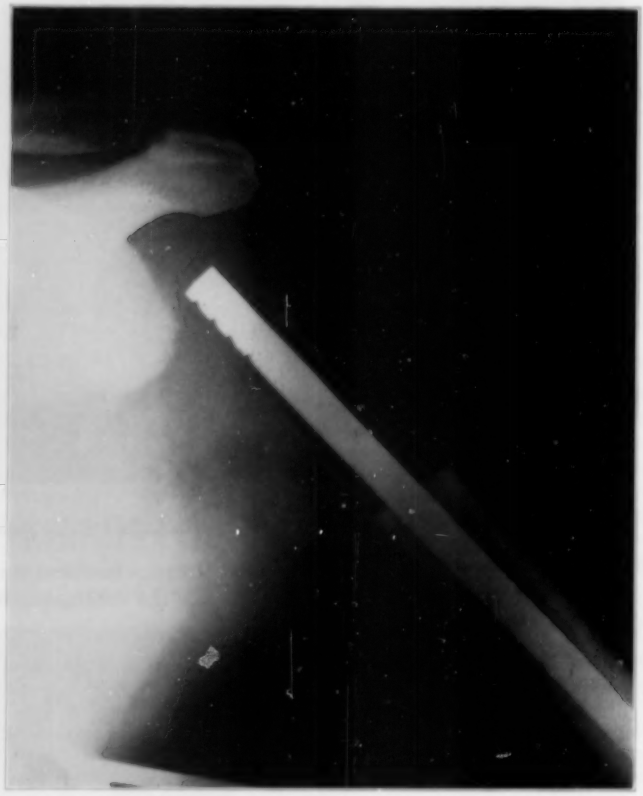

FIG. 4

Fig. 3: The acrylic prosthesis used was ten centimeters long. The rotator cuff was reattached through the drill holes. The long central clover-leaf bar traversed the length of the medullary canal. It was later found that a much larger opening through the prosthesis would have been more practical for re-attaching the rotator cuff.

Fig. 4: Postoperative roentgenogram, showing the prosthesis *in situ*.

FIG. 5

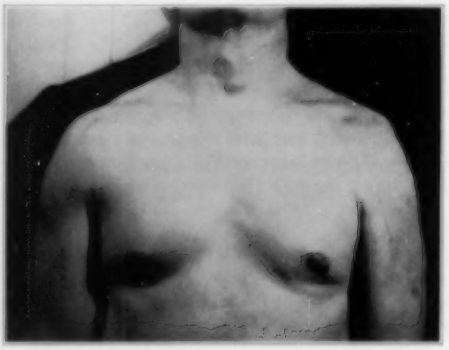

FIG. 6

Fig. 5: Photograph of the resected specimen sectioned transversely. Note that the shaft of the humerus extends about one centimeter beyond the area of discernible tumor tissue.

Fig. 6: Photograph of patient taken a year after his discharge.

all held within the confines of a paper-thin bony shell. This shell was broken in several areas near the greater tuberosity and the head of the humerus, where the pathological fracture had occurred. In this region, neoplastic tissue had extruded beyond the bone proper. The resected portion of the shaft extended approximately one centimeter beyond the line of grossly discernible neoplastic tissue. The microscopic appearance was essentially the same as that of the original biopsy specimen.

The immediate postoperative course of the patient was uneventful. His arm was maintained in the abduction splint for eight weeks. All motions, except abduction, were instituted early. After the splint had been removed, an attempt was made to gain more abduction. Unfortunately, overzealous exertion resulted in forward shifting of the head of the prosthesis in the glenoid fossa of the scapula. The range of motion in his left shoulder was as follows: abduction, 45 degrees; flexion, 15 degrees; extension, 15 degrees; full internal rotation; and external rotation to neutral. Motions of the distal joints were normal.

His last examination was on March 29, 1954. At that time he had essentially the same range of motion as was noted at the previous examination. He accomplishes forward elevation by flinging his left arm forward. He has returned to his previous occupation in a hardware store; he has resumed his other previous activities and recently went on a fishing trip. The head of the prosthesis is now firmly seated. After overexertion, a soft-tissue swelling began to develop along the posterior lower border of the deltoid muscle. This resembled a small portion of separated deltoid muscle.

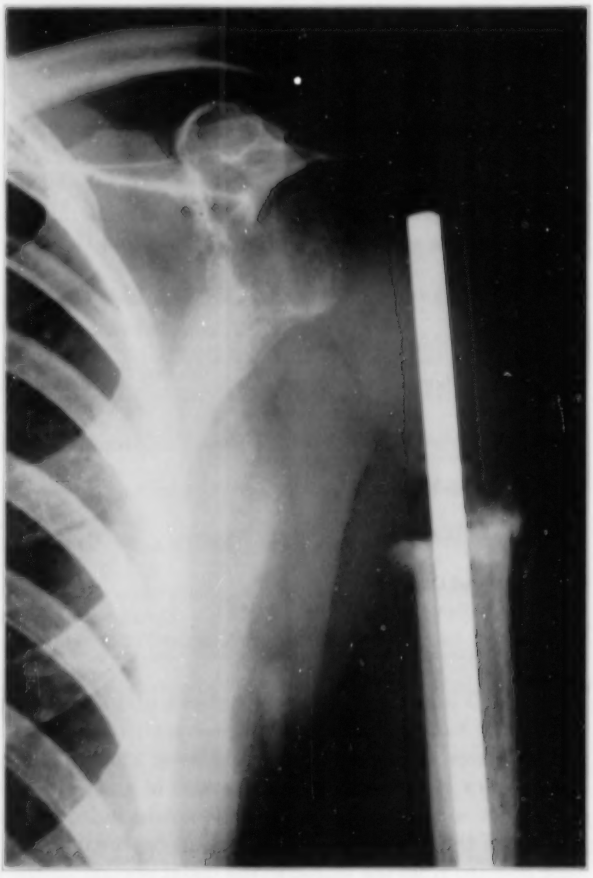

FIG. 7

Roentgenogram of the shoulder made one year after surgery. Irregular new-bone formation was seen around the distal border of the prosthesis.

The swelling gradually increased in size and became annoying to the patient. The region was explored on June 2, 1954. A cyst was revealed, degenerative in type, undoubtedly related to the extensive surgery performed in February 1953. Biopsy showed only a granulomatous tissue reaction, secondary to liquefaction necrosis of degenerated tissue, without any evidence of the original tumor.

Roentgenograms of the left shoulder and chest have been made every three months for the past year. These showed only spur formation of the proximal portion of the humeral shaft at the junction with the base of the prosthesis.

DISCUSSION

Unlike the most frequently occurring type of giant-cell tumor, which involves the region of the knee, tumors of the proximal end of the humerus are usually very large and are often found to involve the entire diameter of the shaft when they are first discovered. This is probably due to the fact that they are not subjected to weight-bearing forces and are concealed deep beneath the deltoid muscle, so that they enlarge to a considerable size before their presence becomes evident.

Meyerding and Simmons listed 124 and 116 cases of giant-cell tumor, respectively; each listed the humerus as involved in eight cases, but they did not specify the site. In other articles, whenever the authors have given the exact location of giant-cell tumors of the humerus, by far the most frequent site has been in the head of the humerus. Christensen had 362 cases, of which twenty-two had involvement of the humeral head; B. L. Coley collected 124 cases, of which five had involvement of the humeral head; and Gross collected seventy cases, of which five had involvement of the humeral head. Thus of a total of 796 cases, forty-eight, or 6.0 per cent., were humeral tumors. (It is not unlikely that there may have been some overlapping of cases from the different authors.)

TABLE I

GIANT-CELL TUMORS REPORTED IN THE LITERATURE

Author	Total No. of Cases	No. with Involvement of Humeral Head	Fatalities from Humeral Tumors	Period of Follow-up (*Years*)
Cahan and coworkers	11	3	2	6 to 22
Coley, W. B.	50	5	3	2 to 4
Windeyer and Woodyatt	38	5	2	3 to 14
Prossor	25	6	0	2 to 6
Geschickter and Copeland	199	8	1	2 to 20
Peirce and Lampe	40	6	0	1¾ to 4½
Andersen	14	1	1	3½

Table I lists those cases of giant-cell tumor of the head of the humerus in which the end results have been reported. These statistics require further clarification. Cahan and his coworkers reported only selected cases which had been subjected to heavy radiation. W. B. Coley reported an additional case of giant-cell tumor of the humerus in which the distal portion was involved. (This is not included in Table I.) He did not mention the location of the tumors in the three patients who died; one of these deaths may, therefore, have resulted from the tumor in the distal portion of the humerus. There were two deaths in Geschickter and Copeland's cases; the location of the tumor was not specified in three of their eight cases in which the humerus was involved. Since agranulocytosis was described as the cause of death in one, only one fatality is ascribed to the tumor in Table I.

Of this group of thirty-four cases of giant-cell tumor, almost all of the head of the humerus, nine had a fatal result. This is a mortality of 26.5 per cent. When the cause of death is described, it is always found to be sarcomatous degeneration. In this regard, Windeyer's statistics are very significant; of his five cases of giant-cell tumor of the head of the humerus, three became sarcomata. Two of these three patients died.

Much of the pertinent literature has stressed the relative benignity of giant-cell tumors. When the end results of treatment are noted, however, giant-cell tumors of the proximal end of the humerus show a high mortality rate because of their sarcomatous potentiality. The treatment of the non-sarcomatous phase of these tumors has consisted in curettage and radiation, either alone or in combination. On the basis of an over-all picture obtained from a brief review of cases in the literature, it is urged that resection be the treatment of choice for giant-cell tumors of the humerus with malignant potentialities. The problem of replacement of the head of the humerus has been simplified by the development and wider use of prostheses.

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ANSWERS TO QUESTIONS

Immunization in Poliomyelitis

(Continued from page 901)

Question:

Dr. Van Riper: The question has been asked about the clinical manifestations. All three types of virus cause the same clinical disease. No one single strain seems to cause a higher percentage of paralytic poliomyelitis than another. The only difference, in fact the only way the strains can be identified and distinguished one from another, is that there is no apparent cross immunity to Type 2 or Type 3; strangely enough, there is not even cross sensitivity. Dr. Salk has investigated hundreds of youngsters whom he has vaccinated and found that they have a degree of immunity to one, two, or three types, or to two of the three; and yet to the types for which they have no demonstrable antibody, they are completely resistant to the first dose of vaccine. In other words, it takes one dose of vaccine to sensitize an individual to that particular strain of virus with which their bodies have had no experience.

Question:

Dr. Van Riper: The question has been asked as to whether or not families will be advised whether their children received vaccine or placebo. As soon as the code has been broken, when the epidemic season is over and actual evaluation is under way, to state and then to county health officers and to physicians, the list will be released, so that every family will know whether or not their child received vaccine or placebo.

A CONTINUING END-RESULT STUDY OF INTRACAPSULAR FRACTURE OF THE NECK OF THE FEMUR *

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The intracapsular fracture of the neck of the femur remains a serious problem for which there is no ready answer. The enthusiastic resort to prosthetic devices, which originated in France and is spreading to all parts of the world, has led or, rather, misled some surgeons, who should know better, to advocate the immediate use of a metal or plastic substitute for the femoral head in fresh fractures of the neck of the femur. There is no really satisfactory substitute for an intact femoral head and neck.

FOLLOW-UP

We started our study of these fractures at St. Luke's Hospital almost twenty-five years ago and have reported previously on 235 cases. This presentation adds 100 consecutive cases, making a total of 335 intracapsular fractures of the femur available for analysis. We previously reported a 95.7 per cent. follow-up study, and in this instance we know definitely the end results in ninety-four of the last 100 cases.

Of the six patients in this series who drifted away before a complete follow-up study, three have been reported as walking with few, if any, symptoms referable to the fractured hip, and on three there are no reports. Having no late roentgenograms on these patients to prove or disprove union of the fracture or the presence or absence of circulatory disturbance in the femoral head, we are forced to exclude these six patients from the study.

Patients Who Comprise This Study

This present series of 100 consecutive patients is drawn from both service and private patients of the Hospital, from all economic levels. The average age of the group was 72.1 years, and 83 per cent. were females. The fact that the average age fell in the early part of the eighth decade is interesting, because, in our three previously reported series, the average age was sixty-five. Whether or not this seven-year increase in the average age in our latest 100 patients is a tribute to better living conditions, improved diet, and resulting greater longevity is a question that we leave to the geriatrists. Twelve of the patients were eighty-five years of age and over; and of these, five were ninety years old and over. Four of the twelve elderly patients died before union could have taken place; two were lost to follow-up; and six have been studied. Uneventful union (Figs. 1-A through 1-C) of the fracture occurred in five of the six who were followed, and one had non-union of the fracture. None of the deaths occurred within the postoperative period. Two of the patients in this last series of 100 were also included in the preceding series of 125 patients. Each of these two had returned to the Hospital with a fracture of the opposite hip. In one, the second fracture has united, but there is a mild circulatory disturbance at the site of the earlier fracture; the other patient has been lost to follow-up. One other patient in this series had had a fracture of the neck of the opposite femur previously and had been treated elsewhere for this earlier fracture.

Mortality and Cause of Death

Of the 100 patients, twelve had died before union of the fracture could have taken place. The average age at death was eighty-one years, and the average time at which

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 26, 1954.

death occurred was sixty-one days after operation. There was only one actual postoperative death,—in a physician, seventy-two years old, with diabetes and cardiovascular disease, who died on the second postoperative day of a coronary occlusion. The causes of the deaths are shown in Table I.

In the five years during which we have studied this series of patients, an additional fifteen patients have died, but the end results are known. Such a mortality is to be expected in 100 patients whose average age falls in the eighth decade.

Patients Available for Analysis

Subtracting the six patients who were lost to follow-up and the twelve patients who died before union of the fracture could have occurred, we have eighty-two patients who are available for complete anlysis. We know the postoperative status of these patients definitely, by clinical examination and by roentgenogram, at an average time of twenty-eight months after operation. Considering the eighty-two patients as one group, there were sixty-eight (approximately 83 per cent.) whose fractures united after treatment with internal fixation, except in one instance to be described subsequently. This percentage may give a false picture of the situation, for nineteen of the eighty-two fractures were without displacement, requiring no manipulation. All but one of the fractures without displacement were treated by internal fixation, and all of them united. The remaining sixty-three

FIG. 1-A

FIG. 1-B

FIG. 1-C

Fig. 1-A: A. N., a ninety-year-old woman, had sustained an intracapsular fracture of the left femur, June 21, 1951. The fracture was reduced and fixed by a three-flanged nail.

Figs. 1-B and 1-C: Anteroposterior and lateral roentgenograms of same hip, eighteen months later, showing united fracture. Patient was then ninety-two years of age and the hip was asymptomatic.

TABLE I

CAUSE OF DEATH IN TWELVE PATIENTS WITH FRACTURE OF THE FEMORAL NECK

Cause of Death	No. of Patients
Cardiovascular disease	6
Cerebrovascular accident	3
Cancer	1
Pneumonia	1
Suicide	1
	Total 12

patients had fractures with displacement, and among them were the vast majority of the complications.

Intracapsular Fractures of the Femoral Neck without Displacement

Fractures without displacement comprise a little over 20 per cent. of all intracapsular fractures of the femoral neck. We have found this incidence of fractures without displacement to be fairly constant, — approximately one in five in all of our previously reported series of fractures of the femoral neck. Fractures without displacement or with minimal displacement should almost invariably do well, because, in all probability, the blood supply to the femoral head has not been so seriously impaired as in the fractures with displacement.

One of the nineteen fractures without displacement which was treated with internal fixation showed evidence of mild, asymptomatic circulatory disturbance in the femoral head, an incidence of 5.2 per cent.

We have previously reported that a small series of eight patients had had uncompli-

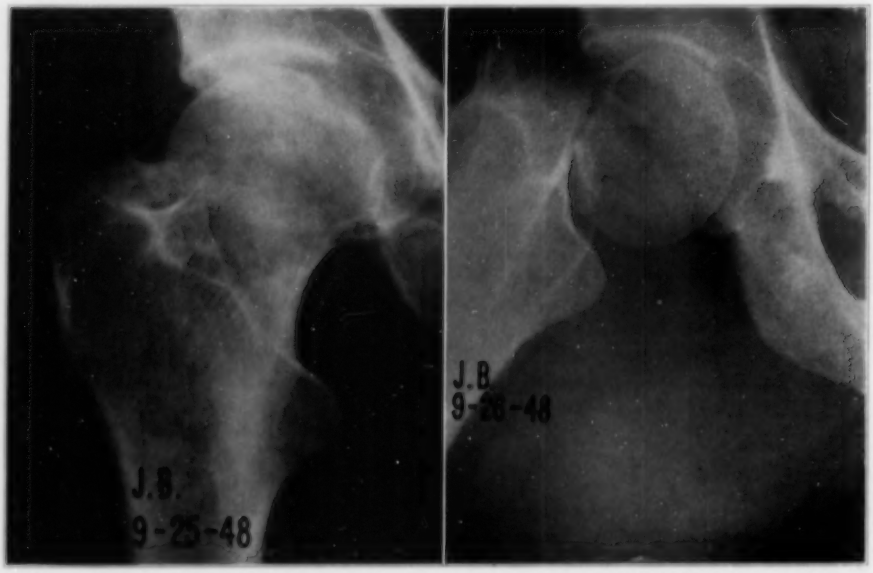

FIG. 2-A FIG. 2-B

Fig. 2-A: J. B., a woman in her seventies, walked into the Out-Patient Department of St. Luke's Hospital, September 25, 1948, and complained of pain in the right hip region and a limp. Symptoms were severe enough to warrant making roentgenograms. The anteroposterior roentgenogram showed an obvious fracture through the femoral neck without displacement. However, the Surgical Resident interpreted this as a normal hip, and the patient was sent home.

Fig. 2-B: During the night, she made a misstep and was brought into the orthopaedic ward the next day with the fracture completely displaced, as shown by this anteroposterior roentgenogram.

cated union of the fracture after treatment by balanced suspension for three to four weeks in bed, followed by ambulation with a Thomas caliper brace and crutches. Unfortunately, these fractures without displacement, which should progress to uneventful union, may not be recognized and may become displaced on attempted unsupported weight-bearing (Figs. 2-A and 2-B). They may also be displaced by carelessness in unnecessary manipulation or even by the driving of the three-flanged nail (as occurred in one instance in a previously reported series).

We feel that internal fixation of these fractures without displacement with careful technique is the best form of treatment. The eighteen patients treated by this method have achieved union of the fracture within four months after injury. The remaining patient, who had entered the Hospital three weeks after injury and was, therefore, not subjected to internal fixation, also achieved uneventful union. This patient, a man of ninety-two years, was followed until his death fifteen months later, after an intertrochanteric fracture of the same hip.

Intracapsular Fractures of the Femoral Neck with Displacement

The intracapsular fracture of the femoral neck with displacement, which requires manipulation in an attempt to secure something approaching anatomical restitution of the fragments prior to internal fixation, remains a constant challenge to surgical skill. There were sixty-three such fractures available for analysis in this series. Adequate reduction by manipulation is often difficult and, in a few instances, impossible. In a previously reported series of patients, we stated that we had abandoned open reduction of fractures with displacement, because we had been able to secure union in only 50 per cent., and because severe circulatory disturbance of the femoral head had occurred in 42.8 per cent. of the united fractures treated by this method. However, among the sixty-three fractures with displacement reported here, we have been forced to resort to open reduction in three instances because we were absolutely unable to reduce the fractures otherwise. Two of the fractures treated by open reduction have united without complication and one has failed to unite.

Of the sixty-three patients with fractures of the femoral neck with displacement treated by manipulation and internal fixation (including three patients whose fractures required open reduction), there has been union of the fracture in forty-nine (77.7 per cent.) and non-union in fourteen (22.3 per cent.). Failure to secure union has, in our opinion, been predominately due to technical errors. Eight of our fourteen failures showed inadequate initial reduction of the fracture and four of these showed faulty insertion of the nail. Failure to secure union occurred in three patients who were not operated upon until ten days to three weeks after sustaining the fracture. We have no explanation to offer for the remaining three failures. We cannot attribute them to technical errors of the Resident Staff, for the Attending Staff has invariably supervised and assisted in the operations on service patients assigned to the residents.

The angle made by the fracture surface with the long axis of the femur has not seemed to be a factor favoring or preventing union. Fractures with angles of 70 degrees or more have readily united. Four of our patients have had fractures with angles greater than 70 degrees; in three the fractures have united, and one patient died before union could have occurred. The size of the head fragment has not been a determining factor in the union of the fractures or in the subsequent fate of the united femoral head.

TECHNIQUE OF REDUCTION AND FIXATION OF FRACTURES OF THE FEMORAL NECK WITH DISPLACEMENT

We have used traction at 90 degrees of flexion and, at times, in full extension-adduction, and, finally, in abduction and full medial rotation in our attempts to reduce these fractures. Perfect re-apposition of the fragments has never been obtained. An 80 to 90

per cent. reduction may be considered adequate, but there is no guarantee that union will ensue. This reduction must be checked by *readable* roentgenograms made in two planes. Without good roentgenograms throughout the reduction and internal-fixation procedures, there is only frustration and failure ahead. At times, we have had difficulty in getting a satisfactory lateral view of the femoral head when the patient is on the operating table.

FIG. 3

As our fixative agent we have almost invariably used the three-flanged nail described by Smith-Petersen. Our only guide is a skin clamp on the skin of the groin; some of our Staff use no guide. In one fracture with a very small head fragment, an immediate rotational osteotomy and insertion of a spline resulted in satisfactory union of the fracture, although the spline perforated the head and was subsequently removed.

We attempt to insert the Smith-Petersen nail through the lower dense portion of the neck of the femur, starting on the lateral surface of the femur at a point approximately one inch below the tubercle formed

FIG. 4-A

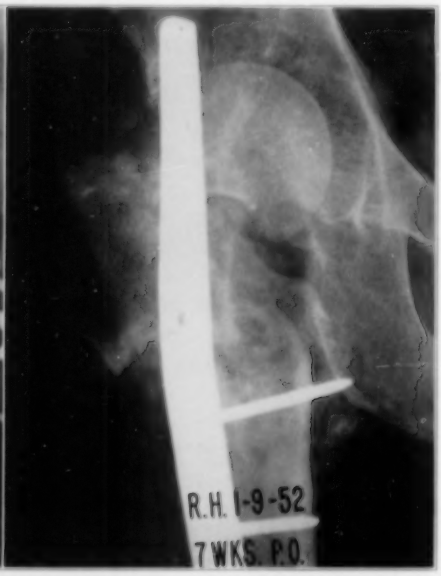

FIG. 4-B

Fig. 3: M. V. Anteroposterior roentgenogram of a fracture with displacement which had been reduced and nailed shows obvious evidence of avascular necrosis thirty-two months after operation. This was first noted by roentgenogram eighteen months after operation. The patient has a wide range of motion, walks without a limp, and has no discomfort.

Fig. 4-A: R. H. Anteroposterior roentgenogram of the right hip made on the operating table shows excellent fixation by a spline after an osteotomy in an ununited fracture of the femoral neck.

Fig. 4-B: Anteroposterior roentgenogram of the same hip, made seven weeks later, shows how the spline had cut through the femoral head.

by the inferior border of the greater trochanter. The nail should enter the posterior inferior portion of the head fragment. With the nail in this optimum position, we believe that there is a diminished shearing stress and, consequently, less likelihood of the nail becoming disengaged from the head fragment. Unfortunately, we are not always able to engage the nail in this optimum position. The average length of the nail used was 3.5 inches. A large woman or a man may require a nail of 3.75 inches up to 4.0 inches in length.

A single drive of the nail in the correct position is highly desirable. This goal was attained in sixty-three fractures. Multiple drives of the nail were necessary in the remainder, two drives in twenty-six, three drives in five, and four drives in two fractures. We consider this to be of some importance, and it was mentioned in ninety-six of the operative notes. These multiple drives seem to have had no influence on union of the fracture; however, of the united fractures subjected to multiple drives of the nail, avascular necrosis developed in 33 per cent., while only a little under 14 per cent. of united fractures in which a single drive was adequate showed this complication.

CIRCULATORY DISTURBANCE OR AVASCULAR NECROSIS IN THE HEAD OF THE FEMUR IN FRACTURES WITH DISPLACEMENT

We have been particularly critical of this unfortunate complication which always seems to threaten our patients who are fortunate enough to achieve union of intracapsular fractures which were displaced. In this presentation and in the previously reported series, we have considered avascular necrosis only as it has occurred in united fractures. Any reference by us to avascular necrosis or circulatory disturbance implies that the fracture in which it occurred had united. The symptoms due to this complication vary from a slight limp to marked progressive disability with pain and, at times, with almost complete loss of motion in the hip joint. In our last 100 patients, among the sixty-eight united fractures, this complication has usually occurred within eighteen months after operation (Fig. 3). In two instances we have seen it occur beyond this time,—in one patient, two years after operation, and, in another, two years and three months after operation. In the fractures with displacement which united, the incidence is twelve of forty-nine (24.4 per cent.). We may expect this complication to occur much more frequently in those fractures in which the blood supply to the femoral head has been seriously disrupted.

Among the nineteen patients with fractures without displacement, of whom all but one were treated by internal fixation, there was one patient who showed minimal circulatory disturbance in the femoral head, an incidence of 5.2 per cent.

Of these thirteen patients who showed roentgenographic or clinical evidence of circulatory disturbance in the femoral head, five showed minimal roentgenographic changes and had few, if any, symptoms. These are essentially satisfactory results. The other eight patients had disabling symptoms and showed marked roentgenographic evidence of serious damage to the femoral head.

SALVAGE OF FAILURES

Twenty-two of the eighty-two patients available for study in this series may be considered failures; fourteen patients have ununited fractures and eight patients have united fractures but with severe circulatory disturbance in the femoral head. These patients comprised the candidates for salvage procedures. We have attempted to improve the situation in sixteen patients with unsatisfactory results by various means and with varying success, as follows:

High Rotational Osteotomy of the Femur and Fixation by Spline or High-Angled Jewett Nail

In the years 1948 to 1951, our attempt to salvage the ununited fractures was usually by means of rotational osteotomy and internal fixation with a spline (in five patients) or a high-angled Jewett nail (in one patient). Only one of these can be, in any sense,

TABLE II

COMPARISON OF SERVICE AND PRIVATE PATIENTS WITH INTRACAPSULAR FRACTURES OF THE NECK OF THE FEMUR

	Service Patients		Private Patients	
	No.	Per Cent.	No.	Per Cent.
Total number	55	55.0	45	45.0
Lost to follow-up.	2	3.7	4	8.9
Died before union could have taken place.	7	12.7	5	11.1
Available for study.	46	83.6	36	80.0
Fractures without displacement available for study (all united).	10	100.0	9	100.0
Non-union of fractures with displacement.	11	30.5	3	11.1
Avascular necrosis in united fractures.	9	25.7	4	12.1

considered a successful salvage or rehabilitation procedure. Since one of us was originally a co-author in a preliminary report suggesting that the spline might have a place in the treatment of non-union of intracapsular fracture of the femoral neck, it seems incumbent on us to state that for this particular situation, that is, for non-union of fracture of the femoral neck, the spline serves no useful purpose. It has cut through the femoral head in every instance as a result of the tremendous leverage exerted by the femoral shaft against the small head fragment (Figs. 4-A and 4-B). The spline is of use in other procedures, including hip surgery, but it should not be employed for ununited intracapsular fracture of the femur.

Hip Prosthesis

Since 1950, we have resorted to the use of a metal prosthesis in our attempt to salvage these unsatisfactory results due to non-union of the fracture or to disabling circulatory disturbance in the femoral head. We have used the Vitallium prosthesis devised by F. R. Thompson of our Service in ten patients, of whom seven had ununited fractures and three had avascular necrosis of the femoral head.

Seven of the ten patients have been satisfactorily rehabilitated, and the status of one patient, still in the Hospital, cannot yet be determined. (The word "satisfactory" denotes relief from pain or marked diminution of pain, and the ability to walk reasonably well with a single crutch or cane or, at times, with no assistance.)

At present, the replacement of the abnormal femoral head with a metallic prosthesis seems to offer the best means of rehabilitation for old people with stiff painful hips due to avascular necrosis or with instability and pain due to ununited fractures.

TABLE III

CIRCULATORY DISTURBANCE IN FRACTURES WITHOUT DISPLACEMENT

Period	United Fractures	Avascular Necrosis	
		No.	Per Cent.
1930–1935 No operation; application of plaster spica.	10	2	20.0
1936–1940 Balanced suspension and bed rest up to one month; Thomas ambulatory splint.	8	0	0.0
1939–1948 Internal fixation with three-flanged nail.	31	4	12.9
1948–1952 Internal fixation with three-flanged nail (except one case).	19	1	5.2

ECONOMIC STATUS OF THE PATIENT

For the first time, we have analyzed the end results in our ward or service patients as compared to the end results in our private patients (Table II). In the current series, there were fifty-five service patients and forty-five private patients. The average age of the service patients was 73.3 years, while that of the private patients was 70.5 years. Of the six patients lost to final follow-up study, four were private patients and two were from the ward service.

The treatment of the patients was almost identical from a surgical and nursing standpoint. There was, however, a surprising difference in the end results achieved by the two groups in this small series. There was non-union of the fractures with displacement in only 11.1 per cent. of the private patients as compared with the incidence of 30.5 per cent. in the service patients. Avascular necrosis or circulatory disturbance in united fractures of the femoral head was found in 12.1 per cent. of the private patients and in 25.7 per cent. of the service patients. The average hospital stay for the private patient was forty-seven days, while the ward patients remained an average of forty days. The ward patients were allowed out of bed on the twentieth day and the private patients on the twenty-third day after operation.

The average length of time which had elapsed between the fracture and the reduction with internal fixation was 3.3 days for the private patients and 4.2 days for the service patients. The average delay before operation on the service patient, as compared with that for the private patient, is one day longer. Twenty-seven of the forty-five private patients were admitted to the Hospital on the day of fracture, and six were operated upon the same day. Of the fifty-five service patients, twenty-two were admitted on the day of fracture, and four were operated upon the same day. In three of our ward patients with unsatisfactory results, however, there had been delays of ten days to three weeks between the fracture and the operation. Probably this series is too small to permit sweeping conclusions about the influence that the economic status of the patients plays in the final end results of fractures of the neck of the femur. The factors which may have favored better results for the private patients are better nutritional status, younger age, earlier admission to the Hospital and, consequently, earlier surgical treatment, and, finally, delayed weight-bearing.

While the Resident Staff has done most of the operations on the service patients, they have been assisted and supervised by the Attending Staff.

COMPARISON OF PRESENT SERIES WITH THREE PREVIOUSLY REPORTED SERIES

Fractures without Displacement

In our previously reported 235 cases, the incidence of this type of femoral-neck fracture was 20 per cent. In this latest series of 100 cases, it was 19 per cent., thus showing that this favorable type occurs rather consistently in one patient of five who sustain a fracture of the neck of the femur.

All of the nineteen patients with fractures without displacement in the latest series progressed to uneventful union of the fracture, but a mild avascular necrosis developed in one patient. We have previously had one patient with non-union of a fracture without displacement in an earlier series. This was due to displacement of the head of the femur when the nail was being driven.

Circulatory disturbances in the head of the femur in fractures without displacement (Table III) should seldom occur if the fractures are handled gently. We have previously reported forty-nine fractures without displacement with circulatory disturbance occurring in six, approximately 12 per cent. We are reasonably certain that most of these complications could have been avoided by gentler handling. In our last nineteen patients with this type of fracture of the femoral neck, there was only one instance of circulatory dis-

TABLE IV

UNION IN FRACTURES WITH DISPLACEMENT

Period and Method of Treatment	Total No. of Patients	Union		Non-Union	
		No.	Per Cent.	No.	Per Cent.
1930–1935 Manipulation and spica.	38	9	23.7	29	76.3
1936–1937 Open reduction, internal fixation.	14	7	50.0	7	50.0
1937–1941 Closed reduction, internal fixation.	33	23	69.7	10	30.3
1941–1948 Closed reduction, internal fixation.	74	59	79.7	15	20.3
1948–1952 Closed reduction, internal fixation (with 3 instances of open reduction).	63	49	77.7	14	22.3

turbance in the femoral head following union, an incidence of 5.2 per cent. This patient is asymptomatic.

Fractures with Displacement

In comparing the end results in the current series in this difficult type of fracture with those previously reported (Table IV), we must go back to the period 1930 to 1935, when our treatment was by manipulation and the application of a double plaster-of-Paris spica dressing to secure fixation. This was called the Whitman abduction treatment, and it is unfair to Royal Whitman to remember him for this alone. In our hands, his method of treatment resulted in 76.3 per cent. incidence of non-union of the fracture. Open reduction and internal fixation reduced the incidence of non-union to 50 per cent. We abandoned the routine open reduction because of this high incidence of non-union of the fracture and also because of a very high incidence of serious circulatory disturbance in the femoral head of those fractures which united.

Closed reduction and internal fixation have yielded much better results. In the previously reported group of seventy-four fractures with displacement, we were able to

TABLE V

CIRCULATORY DISTURBANCE IN THE FEMORAL HEAD IN UNITED INTRACAPSULAR FRACTURES WITH DISPLACEMENT

Period and Method of Treatment	Total No. of Fractures	No. of United Fractures	Circulatory Disturbance in Femoral Head, Avascular Necrosis	
			No.	Per Cent.
1930–1935 Manipulation and plaster spica.	38	9	7	77.7
1936–1937 Open reduction, internal fixation.	14	7	3	42.8
1937–1941 Closed reduction, internal fixation.	33	23	7	30.4
1941–1948 Closed reduction, internal fixation.	74	59	9	15.2
1948–1952 Closed reduction, internal fixation (with 3 instances of open reduction).	63	49	12	24.5

reduce the percentage of ununited fractures to 20.3, thus securing union in over 79 per cent. In this latest group of sixty-three patients, union of the fracture occurred in slightly under 78 per cent., and non-union in 22.3 per cent. We have obviously made no statistical improvement since our last report, and are just about holding our own. We may well have reached an irreducible minimum of non-union in fractures, beyond which our particular limitations will not let us proceed.

Circulatory Disturbance in the Femoral Head in United Fractures

In the matter of circulatory disturbance in the head of the femur in fractures with displacement which have united, we can report no improvement by statistical analysis. In fact, we find a higher incidence of this complication, almost 25 per cent. In addition, one patient with a united fracture without displacement showed mild circulatory disturbance of the femoral head. However, as we have said, in five of the thirteen patients in this series who have shown evidence of circulatory changes in the head of the femur, it has been merely a roentgenographic finding and not a disability.

If we are correct that, in the vast majority of these fractures with definite displacement, the femoral heads are dead and have to be revascularized, it is not surprising that there is a continuing high incidence of avascular necrosis. It is surprising, however, that so many fractures unite and escape this complication.

Mortality

In our previously reported series of 125 patients (1941–1948), there was no death which could be attributed to the operative procedure,—that is, no death within the first week after operation. In the latest group of 100 patients, one death from coronary occlusion occurred on the second postoperative day. Elderly patients tolerate surgery very well indeed; in fact, they take it in their stride without complaints or any evidence of emotional disturbance.

SUMMARY

We have presented a study of 100 additional intracapsular fractures of the neck of the femur with a 94 per cent. follow-up. However, only eighty-two of these patients could be fully studied because six were lost to follow-up and twelve died before the end results could be determined. We cannot consider these deaths as other than unfortunate results, but we cannot evaluate the fractures in these twelve cases.

Eighty-three per cent. of these patients have been women, and the average age of the group was seventy-two years at the time of the fracture. The average age in this group is seven years greater than the average age for the three previously reported series of 235 patients.

All but one of the nineteen fractures without displacement united without complication within four months of the operation. The incidence of union in the group of sixty-three patients with fractures with displacement is almost 78 per cent., which represents no essential change from the incidence in the preceding group of seventy-four patients with a similar type of fracture. Union of these fractures with displacement in this series occurred in an average of 7.5 months after reduction and fixation.

Circulatory disturbance in the femoral head of united fractures with displacement has occurred in almost 25 per cent. of the current series, but only eight of the thirteen patients who have this complication have shown subjective or objective evidence of disability.

Considering the entire group of eighty-two patients available for study, we have had completely satisfactory results,—that is, union of the fracture with no evidence of circulatory impairment of the femoral head in 67 per cent. If we consider the five patients with asymptomatic circulatory disturbance to have had satisfactory results, we might

then claim entirely satisfactory results in 73.1 per cent. Considering the fractures with displacement alone, completely satisfactory results have occurred in slightly under 57.2 per cent. If the four patients in this group with asymptomatic circulatory disturbance of the femoral head are considered to have had satisfactory results, we might again claim satisfactory results in 65 per cent. of the fractures with displacement. In a previous report, we stated that a completely satisfactory end result in two of three of these fractures with displacement was the best that we could achieve. We have not improved on this, but perhaps this is understandable when it is considered that we are dealing with a group of patients seventy-two years old.

We have learned how to salvage some of our unsatisfactory results by means of a prosthetic hip replacement when it has been properly indicated, with due regard to the limitation of such a replacement. We are not ready to render a final opinion on this matter at this time. We have, however, seen no prosthetic hip replacement which can compare favorably with a united fracture with a living femoral head.

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DISCUSSION

Prognostic Implications of Electromyography

(*Continued from page 1013*)

Dr. J. Albert Key, St. Louis, Missouri: In an acute case of poliomyelitis, the anterior horn cells cease to function, due to the fact that some cells are dead and some cells are depressed. The depression may be due to disease inside the cells, or it may be due to conditions resulting from an inflammatory process about the cells.

What Dr. Buchthal and his group are trying to do is to prognosticate what is going to happen to a whole group of cells which supply a muscle through more than one nerve. In peripheral-nerve paralysis, there may be an injury to the motor root; there may be a section of the main motor-nerve trunk or a section of some of its branches which supply a particular part; or the nerve may be compressed as in a "Saturday-night" paralysis, due to pressure, in which the motor component may be thrown out of function. The result may be a motor paralysis or a motor and sensory paralysis; complete recovery may result in both. I wonder whether or not it is possible to correlate these known changes. Knowing the electromyography of peripheral-nerve paralysis, can Dr. Buchthal correlate that with what he is now learning about the paralysis in anterior poliomyelitis? I also wonder whether or not the sympathetic influence may account for the temperature changes he has noted between the permanently paralyzed muscle and the one which is going to recover.

(*Continued on page 1058*)

LESIONS OF THE SKELETON AND OF OTHER MESODERMAL TISSUES IN RATS FED SWEET-PEA (*LATHYRUS ODORATUS*) SEEDS * †

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Kyphoscoliosis, periosteal new-bone formation, and dissecting aneurysm of the aorta in rats fed a diet containing 50 per cent. *Lathyrus odoratus* seeds were reported in a previous paper[7]. Many similarities between the kyphoscoliosis of rats with lathyrism and the so-called idiopathic scoliosis in humans were noted. The studies here presented were primarily undertaken to explore further the pathogenesis of scoliosis.

Albino rats of the Sprague-Dawley strain were used in these investigations. Experimental and control diets were fed to several groups of rats. The rats in the youngest group were twenty-two days old and the rats of the oldest group were one year old when the feeding of the special diets was begun.

The experimental diets were as follows:

DIET 1

	Per cent.
Lathyrus odoratus meal	50.0
Casein	10.0
Cotton-seed oil	2.0
Methionine	0.5
Salt mixture	4.0
Dried yeast	10.0
Starch	17.5
Sucrose	6.0

DIET 2

Same as Diet 1 but with 2 per cent. cod-liver oil instead of cotton-seed oil.

DIET 3

	Per cent.
Lathyrus odoratus meal	50.0
Cornstarch	28.0
Sucrose	6.0
Salt mixture	4.0
Corn oil	2.0
Dried yeast	10.0
Halibut-liver oil, plain	0.2 cubic centimeters per 100 grams

DIET 4

Same as the control diet for Diet 1, but with the concentrated water extract of *Lathyrus odoratus* seed incorporated in a ratio of 6 to 94.

CONTROL DIETS

Diets containing the same ingredients as the experimental diets, but in different concentrations and without the pea meal.

In Table I, data pertinent to age of rats, diets, and treatment are presented.

Roentgenograms were taken under ether anaesthesia at frequent intervals, as presented in Table II.

* This work was aided by a grant from the United States Public Health Service.
† Paper received for publication January 13, 1954.

TABLE I

Group	Age When Feeding Started (*Days*)	Duration of Feeding (*Days*)	Age When Treatment Started (*Days*)	Treatment	No. of Rats	Sex
I	22	35		Diet 1	16	M
I′	22	35		Control diet	13	M
II	23	34–71			34	M
a				Diet 1	8	
b			23	Diet 1 + B_{12}	9	
c			38	Diet 1 + testosterone	8	
d			23 38	Diet 1 + B_{12} + testosterone	9	
II′	23	34–71		Control diet	9	M
III	23	67	23	Diet 2	3	M
III′	23	67		Control diet	3	M
IV	23	10–14			10	M
a				Diet 1	5	
b			23	Diet 2	5	
IV′	23	10–14		Coatrol diet	6	M
V	28	42–140	28		16	M
a				Diet 3	8	
b			28	Diet 3 + casein (10 per cent.)	4	
c			28	Diet 3 + methionine (.75) + casein (10 per cent.)	4	
VI	36	159–216		Diet 1	3	M
VI′	36	216		Control diet	2	M
VI″	36	78		Diet 4	2	M
VII	36	173		Diet 1	1	F
VII′	36	173		Control diet	2	F
VII″	36	78		Diet 4	2	F
VIII	51	124–242			12	M
a				Diet 1	6	
b			51 243	Diet 1 + B_{12} + testosterone	6	
VIII′	51	126–242		Control diet	6	M
IX	51	231			6	F
a				Diet 1	2	
b			174	Diet 1 + testosterone	4	
IX′	51	231		Control diet	4	F
X	59	129–139		Diet 1	5	M
X′	59	139		Control diet	3	M
XI	85	47–63		Diet 1	6	M
XI′	85	50–59		Control diet	3	M
XII	370	204		Diet 1	1	M
XIII	370	196–198		Diet 1	2	F

SKELETAL LESIONS

The skeletal lesions observed in the experimental animals varied according to the age of the rats at the onset of feeding the experimental diets and to the duration of the feeding. In young rats, the earliest changes occurred at the epiphyseal plates and at the

sites of ligamentous and tendinous insertions (Table II).

In the groups of rats three weeks old at the onset of the experiment, the roentgenograms showed a pronounced widening of the epiphyseal plates of the long bones after two weeks of feeding. Sections taken through the epiphyseal plates at that time and one and two weeks later showed a great increase in number and some increase in size of the cartilage cells. These were not arranged orderly in rows, but they appeared in clusters separated by thick, deeply metachromatic septi of cartilage matrix. The cartilage matrix appeared to lose cohesion and to become fibrillated in some areas (Fig. 1). The calcification of the cartilage matrix in the area adjacent to the metaphysis did not seem to be impaired, although it may have been slightly delayed. Endochondral-bone formation at the metaphysis appeared to proceed normally. The bone marrow showed no changes.

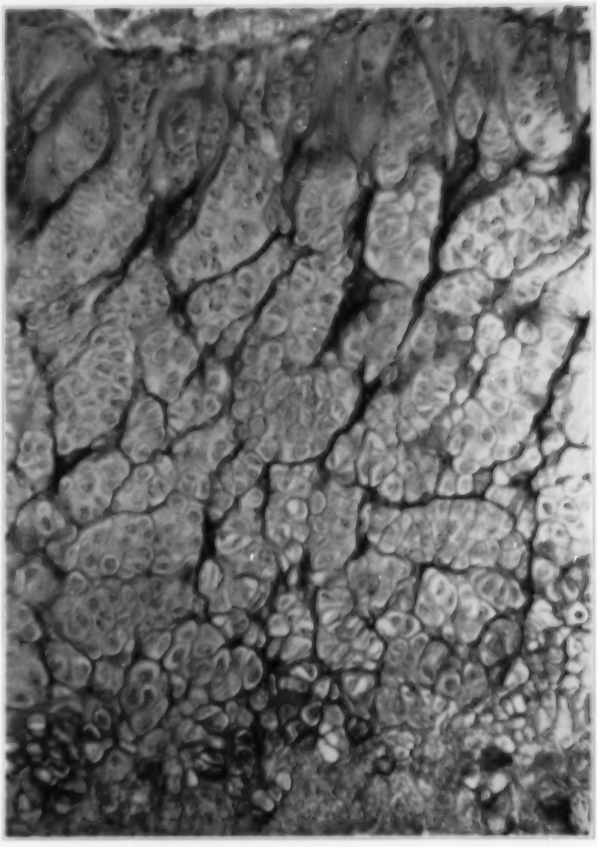

FIG. 1

Photomicrograph of the upper tibial epiphyseal plate of a six-week-old rat which had been fed Diet 2 for three weeks. The plate is about three times wider than that in the control and is distorted. (Toluidine blue stain.)

Toward the third to sixth week of feeding, in some epiphyseal plates the cartilage matrix appeared to disintegrate in a plane between the zone of proliferating cells and the calcified cartilage (Fig. 8). A rent often occurred in that plane. In some cases this rent extended throughout the entire width of the epiphyseal plate. There was some hemorrhage at this area and a few capillaries (Figs. 2 and 9). Slipping of the epiphysis occurred along the line of diminished resistance (Figs. 6 and 10). The periosteum was detached at the metaphysis; this was followed by the formation of new periosteal bone at that site. After the slipping had occurred, the epiphyseal plate was thoroughly disorganized and contained abundant fibrous tissue and fibrocartilage. However, new columns of proliferating cartilage formed in the area adjacent to the metaphysis, and bone growth continued (Fig. 3). At the site of the disorganized plate, the epiphyseal slipping apparently continued to progress in many cases (Fig. 4). These changes were more pronounced in the more actively growing epiphyseal plates, such as the lower end of the femur, the upper end of the tibia, and the upper end of the humerus. The lower epiphysis of the femur usually slipped forward; the upper tibial epiphysis backward; the upper humeral epiphysis downward (Fig. 5); and the lower radial and ulnar epiphyses forward. The upper femoral epiphysis was seen to slip in only a few animals (Fig. 6). The direction of muscle pull and weight-bearing easily

TABLE II

ROENTGENOGRAPHIC STUDIES OF ALBINO RATS FED *Lathyrus odoratus* SEEDS *

Group	Incidence of: Widening of Epiphyseal Plate (*Per cent.*)		Periosteal New Bone (*Per cent.*)		Sternal Protrusion (*Per cent.*)		Epiphyseal Slipping (*Per cent.*)		Kyphoscoliosis (*Per cent.*)		Receding Patella (*Per cent.*)	
IV	100	(30 days)	100	(37 days)	0	(40 days)	50	(40 days)	0	(40 days)	0	(40 days)
II	100	(44 days)	100	(44 days)	95	(44 days)	60	(44 days)	80	(44 days)	0	(44 days)
I	100	(50 days)	100	(50 days)	100	(50 days)	50	(50 days)	75	(50 days)	0	(50 days)
III	?		100	(52 days)	100	(52 days)	100	(52 days)	50	(52 days)	0	(52 days)
VI	100	(63 days)	100	(63 days)	0	(86 days)	35	(63 days)	35	(86 days)	0	(86 days)
VI″	100	(77 days)	100	(116 days)	0	(116 days)	0	(116 days)	100	(116 days)	0	(116 days)
VII	100	(63 days)	100	(63 days)	0	(86 days)	0	(86 days)	0	(86 days)	0	(86 days)
VII″	100	(63 days)	100	(86 days)	0	(116 days)	0	(116 days)	0	(116 days)	0	(116 days)
VIII	100	(100 days)	100	(100 days)	90	(128 days)	20	(128 days)	90	(128 days)	50	(165 days)
IX	100	(100 days)	100	(100 days)	80	(128 days)	85	(165 days)	100	(100 days)	85	(165 days)
X	100	(88 days)	100	(88 days)	100	(226 days)	100	(88 days)	100	(88 days)	100	(226 days)
XI	100	(130 days)	85	(130 days)	35	(130 days)	35	(130 days)	0	(130 days)	0	(130 days)
XII	100	(568 days)	100	(397 days)	0	(568 days)	100	(568 days)	0	(568 days)	0	(568 days)
XIII	50	(568 days)	100	(451 days)	50	(568 days)	50	(568 days)	50	(568 days)	50	(568 days)

* Number in parentheses refers to the age of the rat when the lesions appeared on the roentgenograms. All changes noted were quite pronounced and apparently had occurred several days prior to the day when roentgenograms were made. The usual interval between two consecutive roentgenograms was two weeks. In Groups I through XI, but excluding VI″, the age at which widening of the epiphyseal plate was noted indicates the date the first roentgenograms were made. Reference to the epiphyseal plate, periosteum, and epiphysis is concerned only with the long bones.

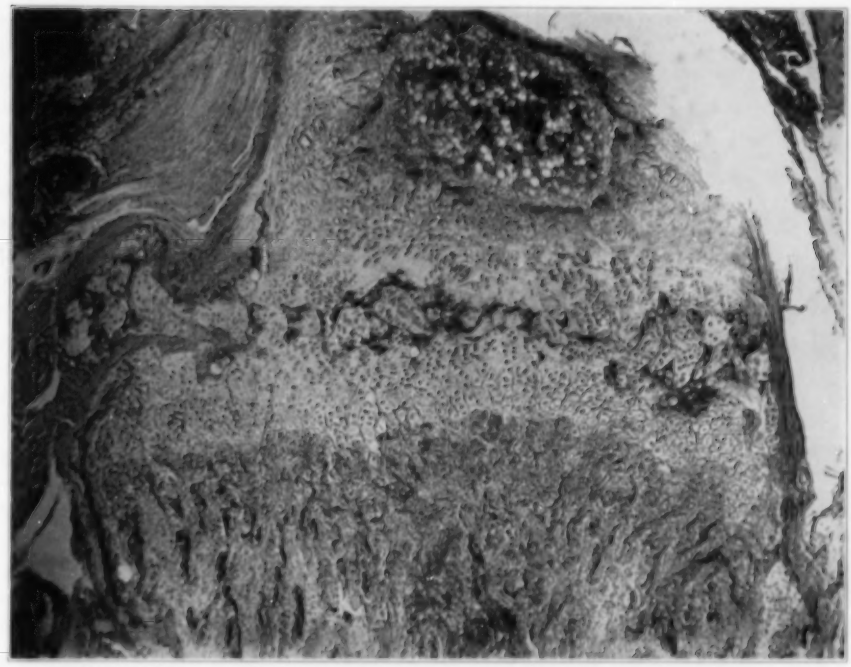

FIG. 2

Section from upper end of the fibula of a 53-day-old rat which had been fed Diet 1 for thirty-one days. The epiphyseal plate is wide. Rents are seen above the zone of calcifying cartilage, extending from one end to the other of the epiphyseal plate. A cartilaginous exostosis is developing at the left end of the plate. (Hematoxylin and eosin stain.)

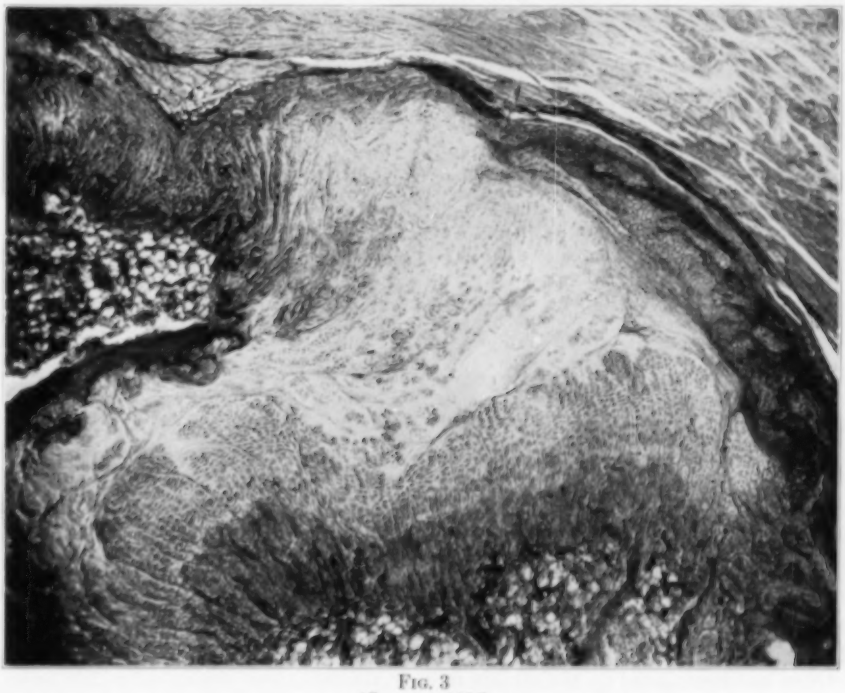

FIG. 3

(*See page 1036*)

Fig. 3: Section from anterior portion of upper epiphyseal plate of the tibia of a 175-day-old rat which had been fed Diet 1 + B_{12} for 124 days. A partial slipping of the epiphysis had occurred. There has been formation of new columns of proliferating cartilage underneath a wide area of disorganized cartilage. (Hematoxylin and eosin stain.)

Fig. 4

Section from upper end of the tibia of a 277-day-old rat which had been fed Diet 1 for 226 days. There has been a major slipping of the upper tibial epiphysis. The epiphyseal plate is very wide and completely disorganized, showing extensive areas of degeneration. (Hematoxylin and eosin stain.)

explain the direction of the slipping in each epiphysis. Similar changes occurred in the epiphyseal plates of the vertebrae.

In some areas of the epiphyseal plate, the rows of cartilage cells were completely interrupted; this produced local defects of ossification in the metaphysis. These defects occurred in epiphyseal plates with and without slipping (Fig. 14).

The older the animal, the less extensive were the lesions in the epiphyseal plate for a given period of experimental feeding. Minimal lesions or no lesions were found in the epiphyseal plates in the rats which were one year old at the onset of the experiment.

The cartilage matrix at the site of the ligamentous insertions also appeared to lose cohesion, and these insertions became loose. The ligaments were partially detached from the underlying bone. Connective tissue appeared at the site of the detachment, and new bone trabeculae which were formed later on were lined up along the direction of pull. These lesions were observed at the insertions of the interspinous, supraspinous, and costotransverse ligaments of the vertebrae. They were more prominent in the younger group of rats than in the older (Fig. 11).

In a previous paper [7], we recorded the histological appearance of periosteal new-bone formation seen in the long bones of the rats fed lathyrus peas. These new periosteal-bone formations appeared first at the site of tendinous insertions and seemed to occur after the periosteum had been lifted by the muscle pull. In the rats three weeks old at the onset of

the experiment, large masses of young, very cellular connective tissue developed by the second week of feeding underneath the lifted periosteum at the site of the tendinous and muscle insertions. In the ground substance, between the young fibroblasts, there were a number of metachromatic granules. Globules of amorphus metachromatic substance were present. There were areas of new cartilage-cell formation, and abundant new bone trabeculae developed adjacent to the bone. No inflammatory cells were seen, nor was an unusual amount of osteoid tissue seen. The earliest areas of new periosteal bone were seen at the insertion of the psoas major into the lesser trochanter, the glutaeus maximus and adductor brevis into the third trochanter, the glutaeus medius into the greater trochanter, and the outward rotators into the trochanteric fossa (Fig. 7). Later on, extensive areas of new periosteal bone were seen

FIG. 5

Roentgenogram of a 188-day-old rat fed Diet 1 for 129 days. The upper humeral epiphysis has slipped downward.

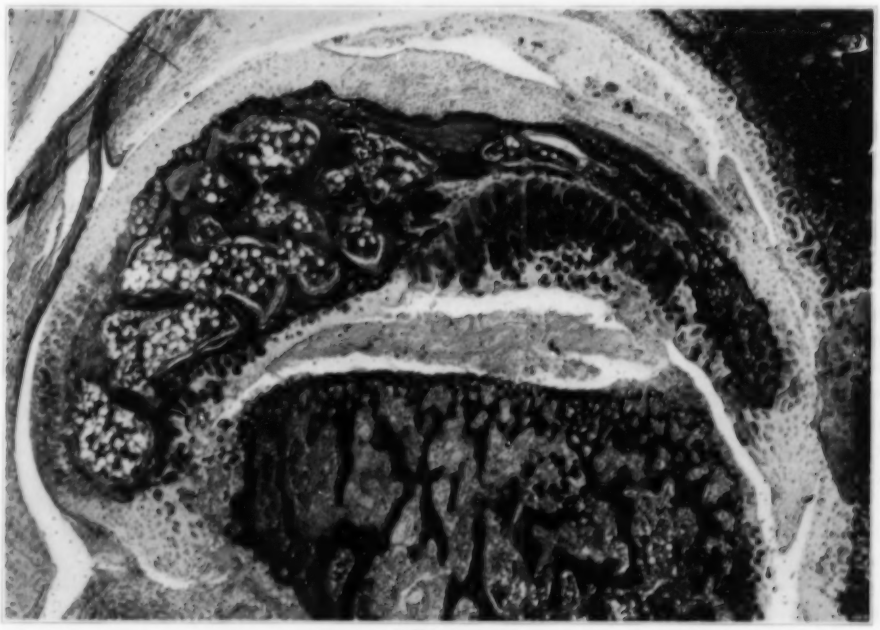

FIG. 6

Photomicrograph showing a mild degree of slipping of the upper femoral epiphysis of a rat, three and a half months old, fed Diet 1 since one month of age. In the epiphyseal plate, a wide rent can be seen partially filled with blood, cartilaginous debris, and very vascular young connective tissue.

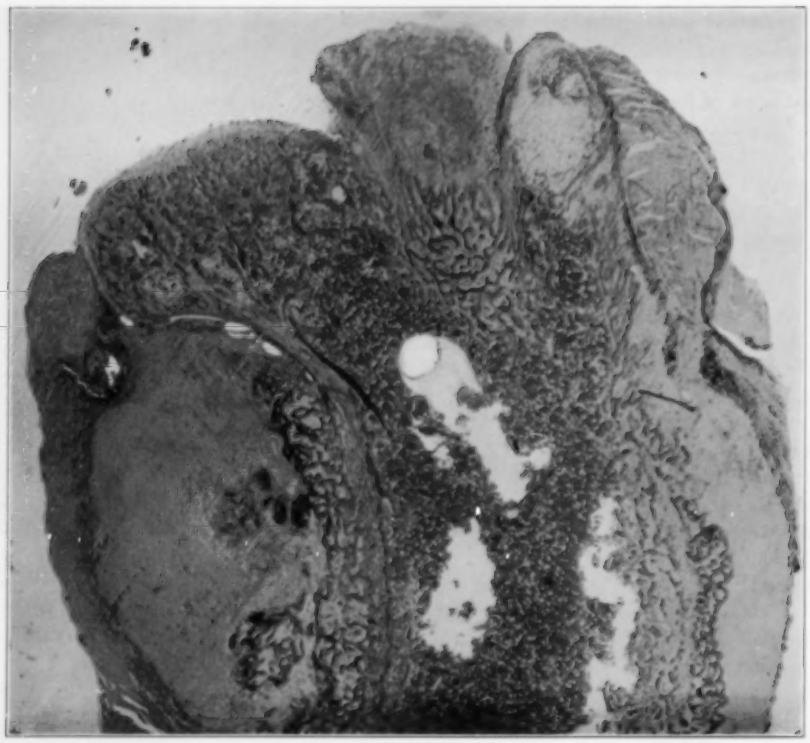

FIG. 7

Section from upper end of the femur of a 53-day-old rat which had been fed Diet 1 for thirty-one days. There are extensive periosteal detachments with much connective-tissue and periosteal new-bone formation. (Hematoxylin and eosin stain.)

over the anterior and posterior surfaces of the femur, some over the posterior surface of the humerus, and only a slight amount below the knee and elbow (Figs. 17, 18-A, and 18-B).

Kyphoscoliosis in the group of three-week-old rats developed after two to four weeks on the diet. The fast development of the kyphoscoliosis in this group of very young animals offered the best opportunity to study the pathogenesis of this deformity. Sagittal sections of the spine suggested that the weakening of the ground substance of the epiphyseal plates of the vertebral bodies and the detachments of the ligaments of the vertebral syndesmosis are both prerequisites for the development of scoliosis. A slipping of the vertebral epiphysis took place at the levels where these two lesions coincided. The slipping produced some detachment of the periosteum from the vertebral body. There was then new periosteal-bone formation which was usually wedge-shaped, with the base facing the portion of the epiphysis overlapping the vertebra. The intervertebral discs did not appear to be abnormal, and the annulus fibrosus remained attached to the slipping vertebral epiphysis. Slipping usually occurred in only one of the two epiphyseal plates adjacent to an intervertebral disc (Figs. 8, 9, 10, and 11).

In some rats, the vertebral epiphyseal slipping occurred rather fast, and there was little chance for repair to take place. A rent occurred in the transitional zone of the vertebral epiphyseal plate which extended throughout the entire width of the cartilaginous plate (Fig. 12). In some animals, a vertebra slipped completely in front of the vertebra beneath, severing the spinal cord (Fig. 13). In other rats, particularly if they had been over

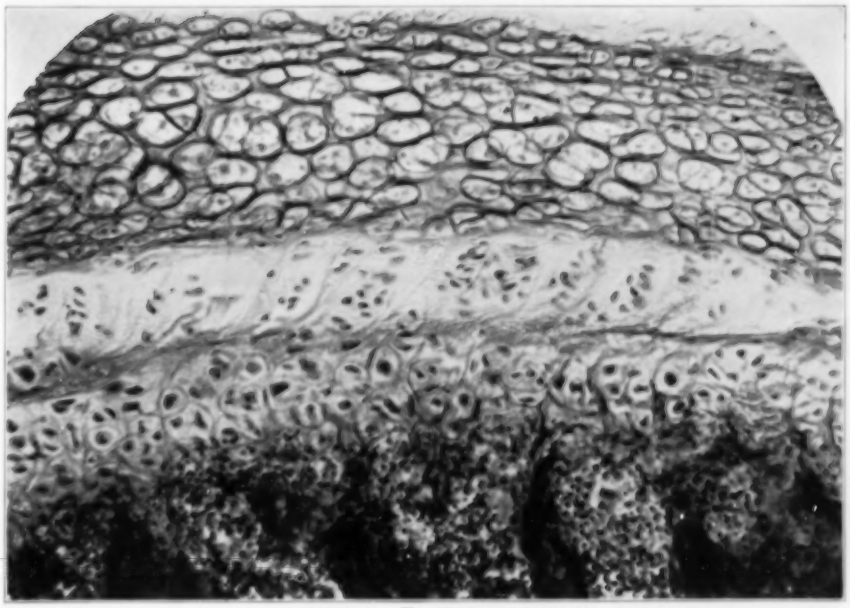

FIG. 8

Epiphyseal plate of a vertebra of a 52-day-old rat which had been fed Diet 1 since the age of twenty-three days. In the transitional zone the matrix appears to be disintegrating. (Hematoxylin and eosin stain.)

FIG. 9

Rent formation in the transitional zone of the epiphyseal plate of a vertebra. The rat was fifty-six days old and had been fed Diet 1 since the age of twenty-three days. (Hematoxylin and eosin stain.)

FIG. 10

FIG. 11

Fig. 10: Twelfth thoracic vertebra of a 56-day-old rat which had been fed Diet 1 + B_{12} + testosterone since the age of twenty-three days. Slipping of the epiphysis, periosteal detachment, and new periosteal bone formation at the anterior aspect of the vertebra are evident. (Hematoxylin and eosin stain.)

Fig. 11: Sagittal section of the vertebrae at the thoracolumbar junction of a 52-day-old rat fed Diet 1 for twenty-nine days. A major slipping has occurred at the upper epiphyseal plate of the first lumbar vertebra with extensive detachment of the periosteum from the anterior aspect of this vertebra. The insertions of the interspinous ligament and of the ligamentum flavum are very loose at the level of the slipping, with extensive formations of fibrous tissue at the site of these insertions. Columns of new periosteal bone can be seen at the loose attachment of the interspinous ligament over the upper aspect of the spinous process of the second lumbar vertebra. (Hematoxylin and eosin stain.)

one month old when the experimental feeding was started, the epiphyseal slipping occurred slowly or not at all. In these cases, a complete rent in the epiphyseal plate was not seen. The anterior half of the epiphyseal plate was often more disturbed than the posterior half,

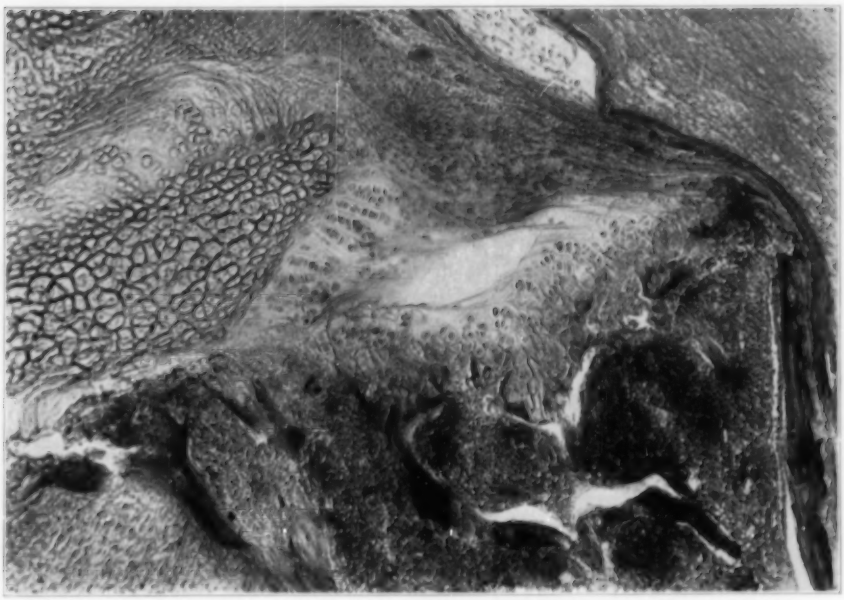

FIG. 12

Fig. 12: Section showing loosening of the matrix of the epiphyseal plate of a vertebra and major epiphyseal slipping. The rat was fifty-six days old and had been fed Diet 1 since twenty-two days of age. (Hematoxylin and eosin stain.)

Fig. 13: Section shows complete epiphyseal slipping between two vertebrae with severance of the spinal cord. The rat was fifty-three days old and had been fed Diet 1 since the age of twenty-three days. (Hematoxylin and eosin stain.)

FIG. 13

and the vertebra gradually became wedge-shaped as new bone was being formed at the posterior part of the vertebra. None was formed at the anterior part (Fig. 15).

Deformities of the thorax were observed in all the younger experimental animals. During the third week of diet, the midsternal segments became angulated and protruded forward. The dorsal and ventral segments of the rib cage became angulated and followed the forward projection of the sternum (Fig. 16). Because of the loosening of the insertions of the costotransverse ligaments, the ribs were angulated downward.

In most rats, a kyphosis developed at the thoracolumbar junction, at the site of the anticlinal vertebra where the greatest stresses occur. One vertebra slipped forward over the vertebra beneath. This slipping occurred only at a few vertebral segments. A

FIG. 14

Section showing a metaphyseal fibrous defect in the spongiosa of a vertebra under a distorted area of the epiphyseal plate. The rat was fifty-six days old and had been on Diet I + B_{12} since the age of twenty-three days. (Hematoxylin and eosin stain.)

FIG. 15

Section showing thirteenth thoracic vertebra of a 199-day-old rat which had been fed Diet I since the age of fifty-nine days. The posterior third of the epiphyseal plate is fairly normal, whereas the anterior part has been completely distorted. Fibrous-tissue defects containing cartilaginous cells are present at the anterior portion of the metaphysis. The cartilaginous plate and the nucleus pulposus are not abnormal. (Hematoxylin and eosin stain.)

little later on, a kyphoscoliosis developed in the mid-thoracic spine. The epiphyseal slipping occurred at that level not only forward but also laterally as the vertebrae rotated (Figs. 17, 18-A, and 18-B). The factors which make possible the rotatory deformity of the thoracic spine appear to be the freer range of rotatory motion and the weaker spinal ligaments in the thoracic vertebrae as compared with the lumbar vertebrae, the deformity of the sternum and of the ribs which was already present, and the extreme caudad direction of the spinal processes of the mid-thoracic vertebrae.

FIG. 16

Fig. 16: Lateral view of the sternum of a 126-day-old rat which had been fed Diet 3 since the age of twenty-eight days, showing advanced deformity.

Fig. 17: Roentgenograms of a 44-day-old rat which had been fed Diet 1 + B_{12} + testosterone for twenty-one days. There are extensive areas of periosteal new-bone formation in the femora, beginning kyphoscoliosis, dislocations of both shoulders, widening and partial slipping of the upper humeral and lower femoral epiphyses, sharp angulation of the sternum, and thoracic deformity.

FIG. 17

FIG. 18-A FIG. 18-B

Roentgenograms of a 199-day-old rat fed Diet 1 + testosterone since age of fifty-one days.

FIG. 19-A FIG. 19-B

Fig. 19-A: Roentgenogram of a 199-day-old rat fed Diet 1 + testosterone for 148 days. There is kyphosis at the thoracolumbar junction. The patella has receded upward along

the anterior aspect of the femur. The upper tibial epiphyseal plates are wide and very distorted.

Fig. 19-B: The same rat fifty-six days later; it had been kept on the same diet. The skeletal lesions have progressed. The patella has receded further. The tibial tuberosity can be seen in front of the lower femoral epiphysis.

FIG. 20

Section from glenoid labrum of a 5-month-old rat which had been fed Diet 3 since one month of age. Clefts are seen in the labrum which is partially detached from the articular cartilage of the glenoid cavity. (Hematoxylin and eosin stain.)

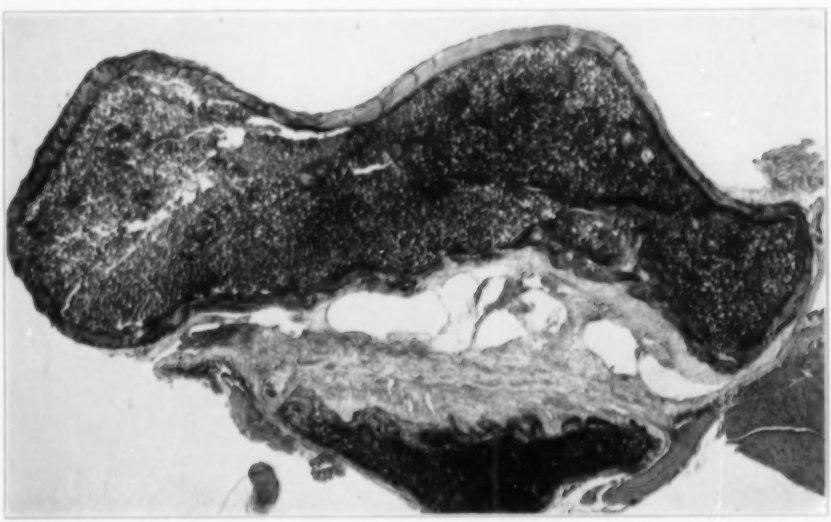

FIG. 21

Section showing diastasis of the sacro-iliac joint of a 198-day-old rat which had been fed Diet 1 since the age of fifty-nine days. There are large cystic cavities in the loose fibrous tissue occupying the joint space. (Hematoxylin and eosin stain.)

FIG. 22

Valgus deformity of the forepaws of a 238-day-old rat which had been fed Diet 4 from twenty-six days of age to 118 days, and Diet 1 from 118 days to 238 days of age.

In the rats of the older groups, the scoliotic component of the deformity was not as pronounced as the kyphotic component. That the rotatory component of the deformity was rare in the older rats is probably due to the lesser severity of the lesions both in the epiphyseal plates and at the ligamentous attachments.

The vertebrae and also the long bones in the young rats were slightly osteoporotic. This osteoporosis may have been due to the relative inactivity of these animals when the epiphyseal slipping and periosteal detachments occurred.

In the younger rats, areas of degeneration and hemorrhage were seen in the cartilage beneath the tibial tuberosity three weeks after the onset of the diet. The tuberosity became loose, was fragmented, and was gradually pulled away from the tibia to which it still remained attached by fibrous tissue. In the roentgenograms of some animals, it was seen that the patella receded upward along the anterior surface of the femoral shaft (Fig. 19). In the older rats, the tibial tuberosity was seen to lie anterior to the femoral condyles where the patella is normally located. The greater trochanter was pulled away from the femur, owing to weakening and widening of the underlying epiphyseal plate.

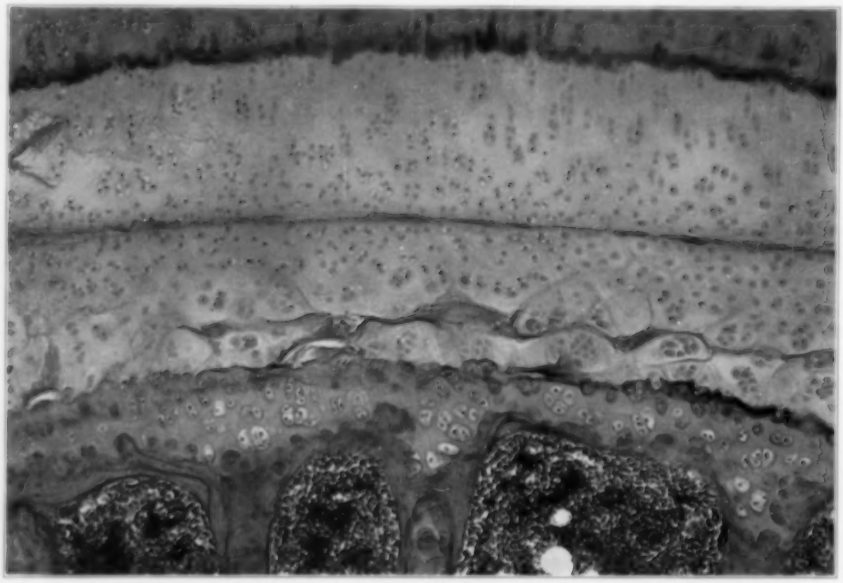

FIG. 23

Section of the shoulder joint of a 5-month-old rat which had been fed Diet 3 since one month of age. Degeneration of the matrix of the joint cartilage is evident. (Hematoxylin and eosin stain.)

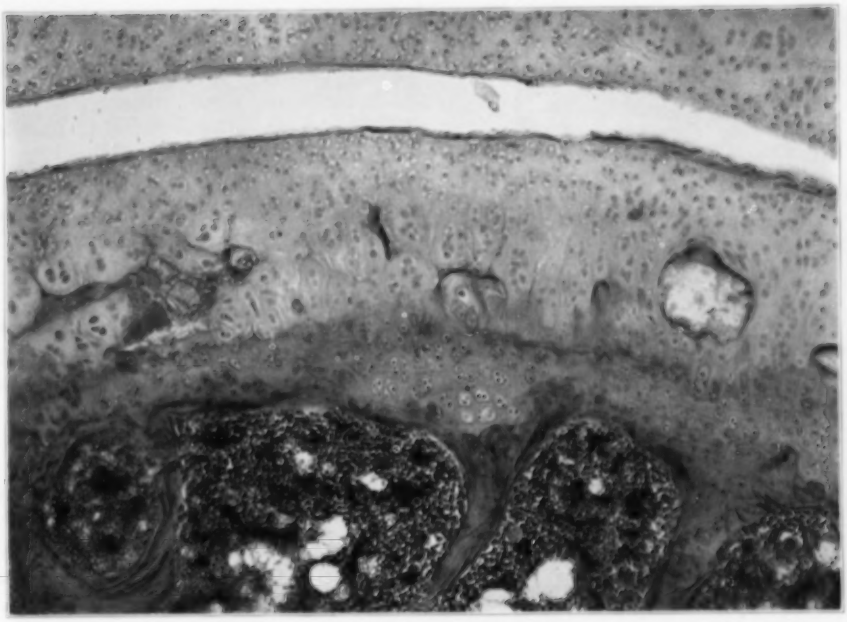

FIG. 24

Section of the shoulder joint of a 5-month-old rat which had been fed Diet 3 since one month of age. Areas of the degenerated joint cartilage have been invaded by capillaries (at the left). A cystic formation can be seen at the right. (Hematoxylin and eosin stain.)

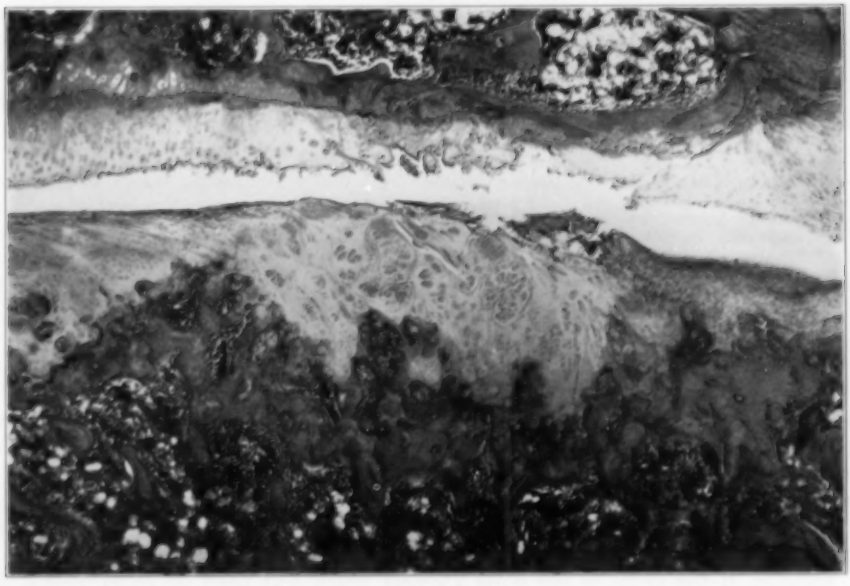

FIG. 25

Section of the joint surface between the patella and the femoral condyles of a 165-day-old rat which had been fed Diet 3 since one month of age. Advanced degeneration of the joint cartilage and subchondral sclerosis are evident. (Hematoxylin and eosin stain.)

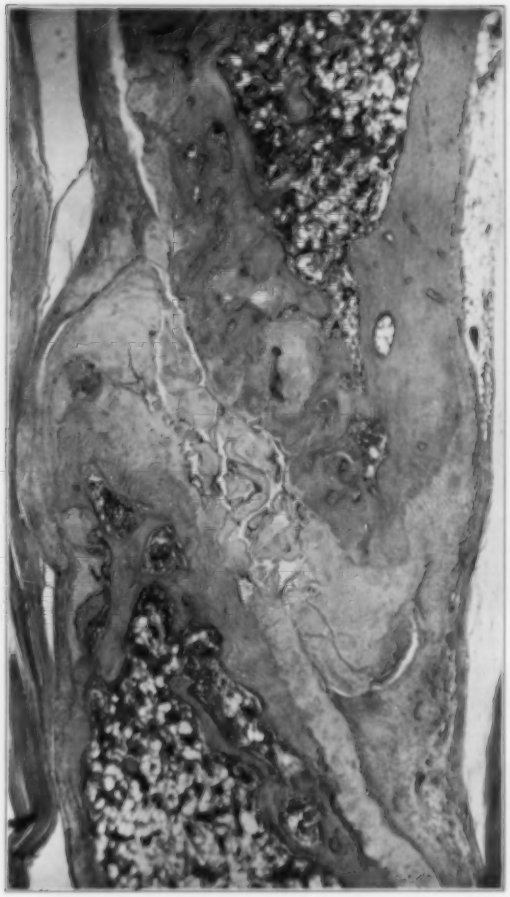

FIG. 26

Section of an articular process of a lumbar vertebra of a 165-day-old rat which had been fed Diet 3 since one month of age. Extreme degeneration and fragmentation of the joint cartilage may be seen. The joint capsule is hyperaemic. (Hematoxylin and eosin stain.)

Subluxations and dislocations of the shoulder were seen in a large number of rats which had been on the diet for over three weeks. There was loosening of the capsular insertions and of the glenoid labrum (Figs. 17 and 20). Slipping and diastasis of the sacro-iliac joint were seen in a large number of animals (Fig. 21). Valgus deformity of the forepaws was observed. This was apparently due to the slipping of the lower radial and ulnar epiphyses and the loosening of the ligamentous and tendinous insertions in the paw (Fig. 22).

Degenerative arthritis was observed in rats which had been on the experimental diet for several months. Two lesions seemed to develop concurrently,—degeneration of the joint cartilage and loosening of the capsular and ligamentous insertions. The cartilage matrix stained red with eosin in areas deep in the joint cartilage. There was fibrillation of the cartilage and formation of nests of cartilage cells. Capillaries invaded the areas of degenerated cartilage; this was often followed by new-bone formation. Circumscribed areas filled with connective tissue were observed in the joint cartilage. The subchondral plate became disrupted and irregular, and the underlying bone was sclerotic. Later on there was moderate thickening and hyperaemia of the synovial membrane. The capsule thickened. Cartilage and bone proliferations were observed at the previously loosened capsular insertions (Figs. 23, 24, 25, and 26).

A lesion resembling lesions seen in Legg-Perthes disease was observed in one rat. Sections of the upper end of the femur showed the femoral head to be necrotic, fragmented, and flat. The epiphyseal plate was reduced to a few scattered areas of cartilage cells. The metaphysis was very wide. Areas of fibrous tissue and cartilage were present in the metaphysis and deep in the femoral neck. There was no articular cartilage; instead, very cellular fibrous tissue covered the distorted femoral head (Fig. 27). Necrosis and flattening of the femoral head was suggestive in roentgenograms of other rats. Unfortunately, sections of the upper end of the femur were made in very few animals, and we do not know how frequently these lesions of the femoral head developed.

Sections of the spine in the older animals which had been on experimental diets for several months revealed that the epiphyseal plate was very narrow, although not completely obliterated. A minimal degree of epiphyseal slipping had taken place at a few levels. There were degenerative changes in the intervertebral discs with a great number

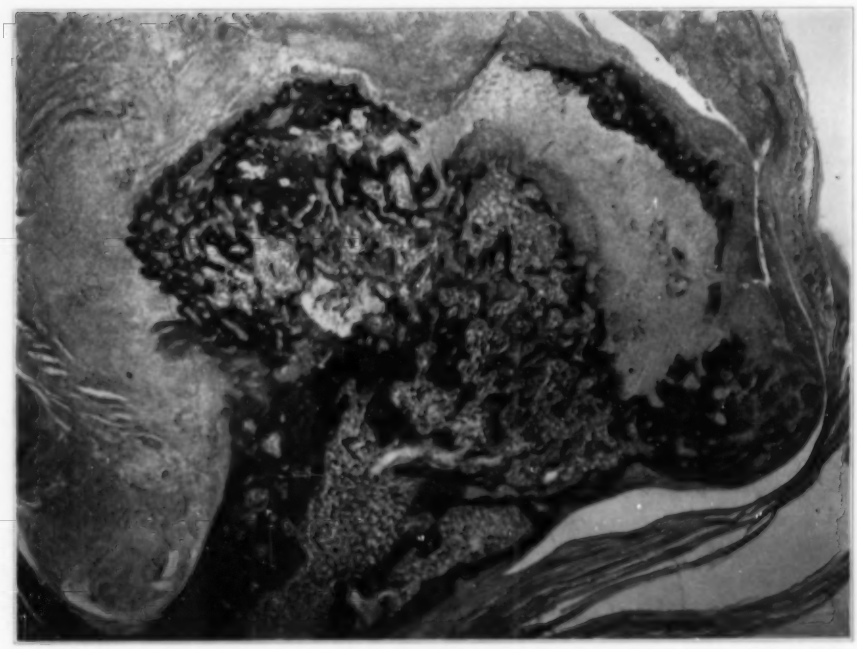

FIG. 27

Section from a Legg-Perthes-like lesion in the femoral head and neck of a 198-day-old rat which had been fed Diet 1 since the age of fifty-nine days. (Hematoxylin and eosin stain.)

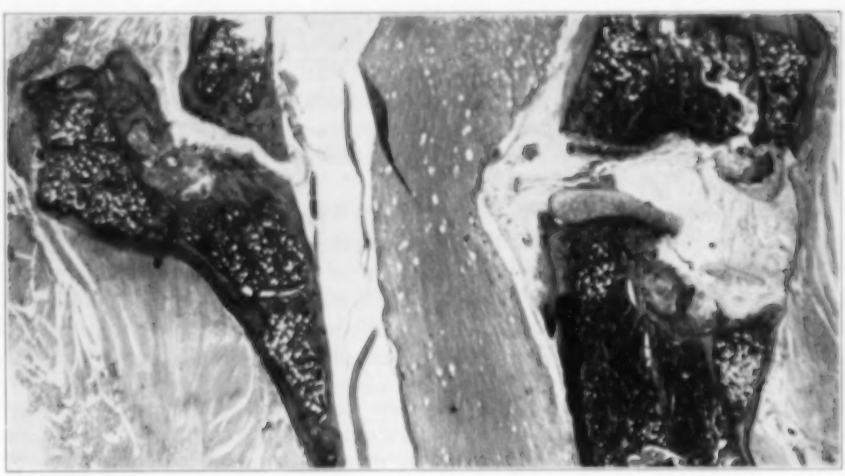

FIG. 28

Sagittal section of the lumbar vertebrae of a 574-day-old rat, which had been fed Diet 1 since 370 days of age. There is protrusion of the intervertebral disc, pressing against the cord. The anterior half of the epiphyseal plate has collapsed, and a great amount of fibrous tissue and intervertebral-disc material has escaped into the spongiosa of the vertebra. At the same level there are defects filled with fibrous tissue in the spinous process at the site of the insertions of the interspinous and supraspinous ligaments. (Hematoxylin and eosin stain.)

of cartilage cells in between the fibers of the annulus. Blood vessels and areas of hemorrhage and of calcification were present in the degenerated discs. The nucleus pulposus was seen to be degenerated and, in some cases, calcified. Herniations of the disc posteriorly

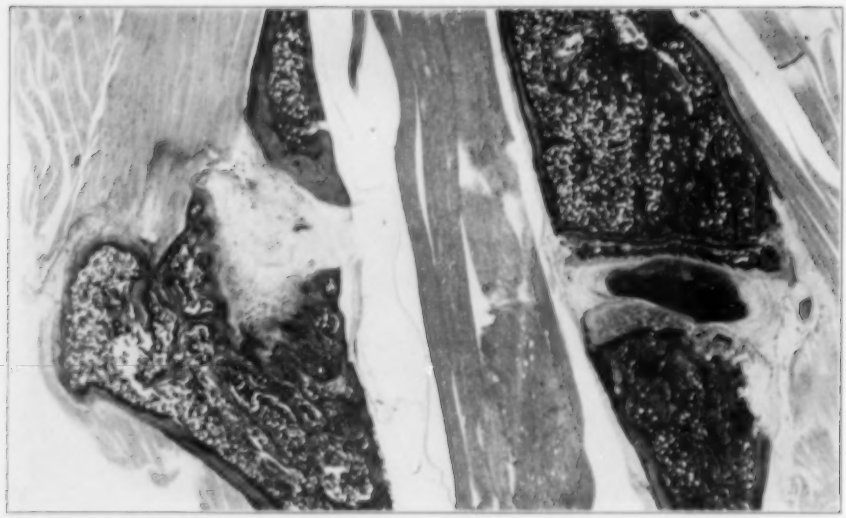

FIG. 29

Sagittal section of the lumbar vertebrae of a 521-day-old rat. This rat had been fed Diet 4, starting at thirty-six days of age. At 118 days of age, the diet was changed to Diet 1. At 370 days of age, the diet was changed again to Diet 1 + B_{12} + testosterone. There is an extensive area of loose fibrous tissue and fibrocartilage in the spinous process at the level of the intervertebral-disc degeneration. Spur formation at the anterior margin of the upper vertebra and a large defect in the lower vertebra can be seen. (Hematoxylin and eosin stain.)

and into the cartilaginous plates were observed (Fig. 28). Collapse of extensive portions of the cartilaginous plate and protrusion of the intervertebral disc into the vertebral body were seen. Loosening of the insertions of the interspinous and supraspinous ligaments was more pronounced at the level of these disc changes than at other levels with normal discs. There were some areas of hemorrhage and an abundance of cartilage cells and fibrous tissue at the site of these tendinous insertions. Spurs were observed at the anterior margins of the vertebral bodies. The spurs occurred at the site of loosened insertions of the anterior longitudinal ligament (Figs. 28 and 29).

The roentgenograms of rats of the older groups revealed rather thick cortical bone and dense metaphyses. Histological sections demonstrated areas of dense bone with mosaic patterns and very thick bone trabeculae. The cement lines between these bone trabeculae were wide and stained deep blue with hematoxylin, resembling the mosaic patterns seen in human patients with Paget's disease. These mosaic patterns were present mostly at areas of major stress, such as the posterior aspect of the tibia after slipping had occurred. However, bone resembling that seen in Paget's disease was seen to extend throughout the entire width and along half of the length of the femoral diaphysis in one rat (Fig. 30).

LESIONS OF SKELETAL MUSCLES, FASCIAE, AND APONEUROSIS

Microscopic studies of the skeletal muscle in the experimental animals revealed no abnormalities except for a slight increase in the number of nuclei. In the literature on experimentally produced lathyrism, the most common symptom reported is spastic paralysis. Length-tension studies were carried out on 58-day-old rats which had been fed the experimental diet since the age of three weeks. These studies seem to point to the absence of spasticity, our interpretations being based on unpublished work on spasticity in white rats.* However, the animals do have an unsteady and jerky gait when maintained

* These studies and the ones mentioned in the following paragraphs on muscle metabolism were made by Shepard and will be reported in detail in another paper.

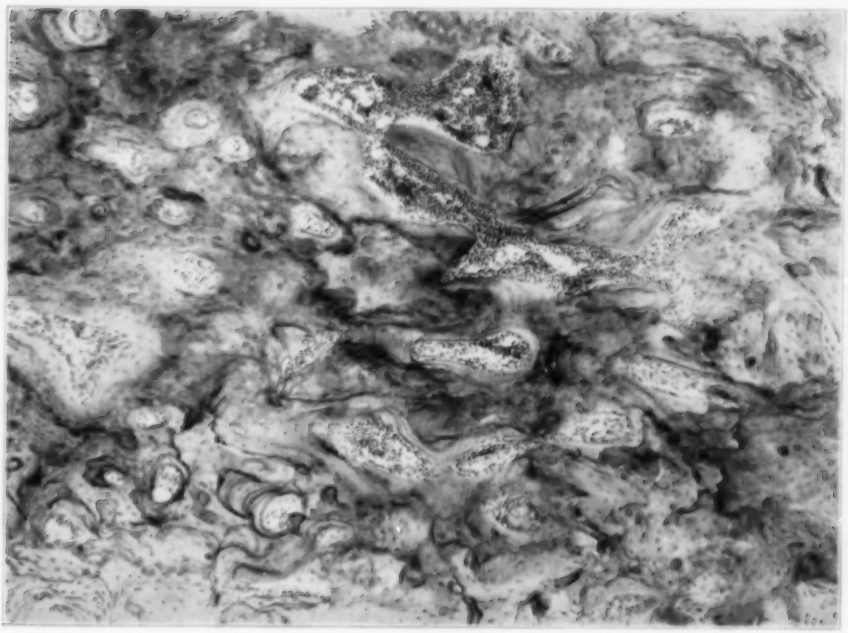

FIG. 30

Photomicrograph showing Paget-like bone trabeculae in the mid-femoral shaft of a 165-day-old rat which had been fed Diet 3 since one month of age. (Hematoxylin and eosin stain.)

for longer periods of time on the experimental diet. It is apparent, then, that the bone changes precede the development of muscle spasticity. The poorly coordinated gait and the spasticity may be due to pain following the periosteal detachments, the slipping epiphyses, degenerative arthritis, or, in many rats, the cord damage produced by the slipped vertebrae.

A number of oxygen-consumption analyses of muscles were carried out on experimental and control rats. These showed that in experimental rats oxygen consumption is higher than that of the controls. Oxygen-consumption studies of the soleus muscles of the experimental animals show a significantly higher $Q\text{-}O_2$ (volume of oxygen liberated per milligram of tissue per hour) than in the control animals.

Muscle-creatinine determinations on the soleus muscle indicate no difference between the experimental and control rats.

Geiger, Steenbock, and Parsons, in 1933, remarked on the high frequency of abdominal and inguinal herniae in rats with lathyrism. We observed large inguinal and abdominal herniae in rats after several weeks on the experimental diet, although we did not make a special study of the herniae and we are unable to give any statistical data. In one of the animals, a large segment of the intestine descended into the scrotum. Electron-microscopic studies of the fibers of the tail tendon of experimental animals after different periods on the experimental diet revealed nothing abnormal in the structure of the collagen fibers. The periodicity of the collagen fibers was the same in the experimental animals as that in the control animals. It may be supposed, then, that the herniae are not due to a defect of the collagen fibers but rather to a fault of the ground substance.

DISSECTING ANEURYSM OF THE AORTA

The incidence of dissecting aneurysm of the aorta was related to the age of the rat when the experimental diet was started. In several groups of 22-day-old and 23-day-old

TABLE III

WEIGHT CHANGES IN RATS FED *Lathyrus odoratus* SEED *

Group	Increase in Weight at Approximately the: Onset of Roentgenographic Findings	End of Feeding
IV	7.7 ± 0.5 grams (7 days)	
II		
a	81.4 ± 4.7 grams (22 days)	100.5 ± 11.3 grams (34 days)
b	70.6 ± 4.4 grams (22 days)	67.0 ± 13.1 grams (34 days)
c	76.1 ± 4.0 grams (22 days)	All dead after 34 days
d	88.8 ± 3.7 grams (22 days)	73.3 ± 10.0 grams (34 days)
III	18.7 ± 4.4 grams (29 days)	
I	80.5 ± 4.9 grams (34 days)	
VIII		
a	138.2 ± 7.6 grams (96 days)	127.5 ± 12.9 grams (124 days)
b	144.0 ± 5.3 grams (96 days)	156.2 ± 23.6 grams (124 days)
IX	69.7 ± 3.4 grams (96 days)	81.8 ± 2.5 grams (124 days)
XI	35.3 ± 4.4 grams (26 days)	
XI'	28.5 ± 8.5 grams (26 days)	

* Number of days in parentheses refers to the duration of feeding the experimental diet at the time the weights were taken. All weights are expressed in terms of ± one standard error. Analysis of Groups II, VIII, and XI show that there are no statistical differences of weights at the 3 per cent. level between the subgroups on a given date.

rats, dissecting aneurysms of the aorta occurred in 75 per cent. of the animals (Table IV). Deaths due to the aortic lesions occurred as early as twelve days after the experimental diet had been started. No aneurysms were produced when feeding had been started later than fifty-one days of age. The dissecting aneurysm occurred either in the ascending aorta, arch, or in the upper thoracic aorta. No aneurysms were noted in the abdominal aorta.

The lesion started in the media. The elastic fibers and the muscle fibers did not appear to be abnormal at first. There was loss of cohesion of these fibers, seemingly due to a defect of the binding power of the ground substance. There was then patchy necrosis of the smooth muscle cells. The elastic fibers remained unaltered. The intima ruptured at the site of weakening of the media, and blood penetrated and dissected between the degenerated areas of the media. The adventitia usually ruptured, and the blood extravasated, producing hemothorax or hemopericardium (Fig. 31). In some of the younger rats, sacrificed two and three weeks after the onset of the experimental diet, dissecting lesions were observed with attempts at repair. There was very cellular connective tissue patching the defect of the arterial wall.

No lesions were observed in the smaller arteries, veins, or in the capillaries; however, no detailed studies were made of these vessels.

No abnormalities were observed in the lungs, liver, spleen, and kidney. The pancreas was normal in all rats examined except for one rat which was started on the experimental diet at fifty-one days of age and was sacrificed at 281 days of age. This rat had partial necrosis of the pancreas with areas of regeneration. Dr. Warren O. Nelson, from the Department of Anatomy, studied the pituitary, thyroid, adrenal, and prostate glands, and the testicles of five rats fed the experimental diet during different periods of time. In all of these rats skeletal lesions had developed. Severe abnormalities were found in the testes of two rats which had been on the diet for 216 days. The testes of these two rats showed

partial arrest of spermatogenesis, sloughing of cells, and giant-cell formation. In two animals which had been on the diet for 120 days, the testes contained occasional tubules which showed early changes of the type described for the two older rats. The fifth rat which also had been on the diet for 120 days had histologically normal testes. The prostates of the two older rats were atrophic, and there was an increased number of basophilic cells in the pituitary glands (castration effect). Nothing remarkable was observed in the other endocrine glands.

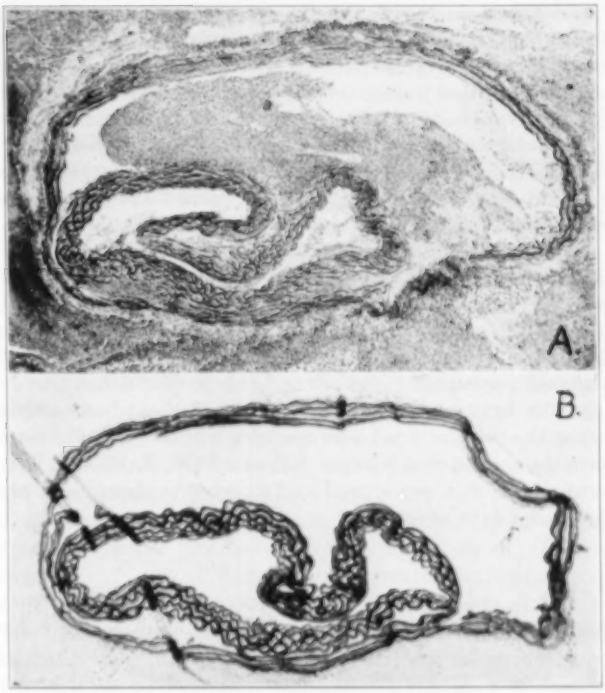

FIG. 31

Dissecting aneurysm of the upper thoracic aorta. The rat expired at thirty-four days of age and had been fed Diet I for only twelve days.
A: Hematoxylin and eosin stain.
B: Orcein stain for elastic tissues. The elastic fibers are well preserved.

Treatment with Vitamin B_{12} and Testosterone

Vitamin B_{12} was incorporated into the experimental diet of a series of rats (Tables I and III). The younger rats received vitamin B_{12} as rubramin crystalline at a level of 0.05 per cent. of their diet. The older rats received vitamin B_{12} as bevidox concentrate at a level of five milligrams a day per rat. These experiments indicate no apparent difference in the progress of the lesions in animals treated with vitamin B_{12} and those not so treated.

TABLE IV

DISSECTING ANEURYSM OF THE AORTA IN ALBINO RATS

Group	No. of Rats	Age When Feeding Started (*Days*)	Duration of Feeding (*Days*)	Incidence of Aneurysm (*Per cent.*)	Incidence of Hemothorax (*Per cent.*)	Age When Hemothorax Occurred (*Days*)
I	16	22	35	75	69	34–56
II	34	23	34	74	59	41–57
V	16	28	42–140	31	31	63–154
VI	3	36	159–216	0	0	
VIII	12	51	124–242	8	8	101
IX–XIII	12	51–370	47–231	0	0	

Concurrently with the above experiments, we also ran a series of studies (Tables I, II, and III) on the effect of testosterone cyclopentylpropionate on the development of the skeletal lesions. Intraperitoneal injections of five milligrams of testosterone in 0.2 milliliter of saline solution were given three times a week. As with vitamin B_{12}, the testosterone was found to be of little or no therapeutic value. Histological studies of the endocrine glands of the older group of animals revealed pituitary inhibition by the testosterone, which resulted in testicular atrophy and arrested spermatogenesis. It should be emphasized, however, that no differences in the epiphyseal plates of treated and untreated animals could be found.

Use of testosterone and vitamin B_{12} together was also tried (Tables I and III). The dosages were those indicated previously. Again, the treatment failed to arrest the development of the disease.

In the groups of rats which were fed the experimental diet containing cod-liver oil instead of cotton-seed oil, skeletal changes similar to those seen in the other groups of animals developed.

We have also found that many of these bone changes could be produced in rats when the concentrated water-soluble extract of *Lathyrus odoratus* seeds was incorporated into the control diet (Groups VI″ and VII″, Table II). This extract constituted only 6 per cent. of the diet, yet it produced a severe kyphoscoliosis in one 36-day-old male after only forty-one days of feeding.

DISCUSSION

It is possible that the disorders here described may have a common underlying pathogenesis, since they all can be produced in rats fed with diets containing *Lathyrus odoratus* seeds. The lesions occurred in areas in which the ground substance contains chondroitin sulphate as the only mucopolysaccharide or the main mucopolysaccharide. All of the lesions encountered could have been due to a defective formation or an excessive destruction of the chondroitin sulphate of the ground substance. A crystalline product has been extracted from the lathyrus seeds, which appears to be the active factor responsible for these lesions.

The following observations made in the experimental animals during the course of these studies seem to be of particular significance: A high oxygen consumption was found in the muscles; there was partial arrest of the spermatogenesis and giant-cell formation in the testes; and there was resorption of the foetus in pregnant rats fed the experimental diet (unpublished studies with F. W. Stamler). All of these are known to occur in animals fed vitamin-E-deficient diets. Lee reported that in rats fed meals containing singletary pea (*Lathyrus pusillus*) curvature of the spine, enlargement of the epiphyses of the long bones, exostoses, and paralysis of the hind quarters developed. When twenty milligrams of alpha-tocopherol was given per day to rats fed the singletary-pea diet, over one third of the rats were symptom-free. However, in recent experiments (unpublished), we have not been able to prevent the development of the lesions in rats fed *Lathyrus odoratus* meal with the administration of alpha-tocopherol, the same dosage being used as that reported by Lee. Sanyal has extracted an oil from the edible pea (*Pisum sativum*) which he considers to be an anti-vitamin E. The possible relationship between vitamin E and the ground substance was pointed out by Miller and Dessert who suggested that one important function of vitamin E may be to regulate hyaluronidase activity *in vivo*. It has not been proved, however, that vitamin E is connected with the synthesis of chondroitin-sulphuric acid nor that the active substance of *Lathyrus odoratus* seeds is a vitamin-E antagonist. We did not observe any appreciable lesions in the epiphyseal plates of guinea pigs on vitamin-E-deficient diets. We have had a group of rats on vitamin-E-deficient diet for three months; so far we have not observed any skeletal lesions in the roentgenograms.

Every one of the disorders observed in rats fed with *Lathyrus odoratus* seeds has a

counterpart in human diseases of unknown etiology and pathogenesis. From our studies on the experimental animals, it seems possible to understand now the pathogenesis of these diseases in human patients. The etiology, however, of these diseases remains unknown.

The so-called "idiopathic" scoliosis in humans occurs in adolescents, and the deformity ceases to progress as soon as the skeletal growth of the spine is completed,—that is, as soon as the epiphyseal plates become obliterated. Close observation of the roentgenograms of these patients with rapidly progressing scoliosis points to defects of the bone of the vertebrae, particularly in the areas adjacent to the cartilaginous plate[6]. The deformity becomes more severe when the mid-thoracic vertebrae are involved. It seems logical, therefore, to assume that in scoliotic patients there is a defect in the epiphyseal plates, just as there was in the rats of our experiments. Diseases in children which produce widening and weakening of the epiphyseal plate, such as rickets or even vitamin-D resistant rickets, usually do not cause scoliosis. It appears that weakening of the epiphyseal plates alone will not produce scoliosis, unless it is accompanied by weakening of the ligamentous insertions into the vertebrae and ribs which help to stabilize the spine. A better name for idiopathic scoliosis would be *adolescent scoliosis*. Rare cases of scoliosis are seen in children[3]; the deformity usually starts before the age of three years and may progress to severe deformity. We assume that in *infantile scoliosis* there is the same underlying disturbance in the cartilage but to a more severe degree.

Roentgenographic skeletal surveys, now underway, of patients with adolescent scoliosis show that the skeletal lesions are not localized in the spine and thorax. Slight detachments of the tibial tuberosities, minimal slipping of the lower femoral epiphysis, the greater trochanter, and the olecranon have been observed.

Juvenile or *adolescent kyphosis* frequently develops at about the thirteenth to the sixteenth year of age, and the lower thoracic vertebrae are involved in most cases. Scheuermann rejected Schmorl's theory which maintains that prolapse of the nucleus pulposus is the primary factor in adolescent kyphosis. Scheuermann, basing his observations on clinical and roentgenographic studies, stated that "the primary cause must be sought in the line of growth, which either becomes pressed into the spongiosa or whose development anteriorly is behindhand". We believe that the pathogenesis of adolescent kyphosis can now be explained on the basis of defects of the epiphyseal plates of the vertebrae, similar to the lesions described in our experimental animals. Metaphyseal fibrous defects were frequently seen in the vertebrae of young rats, without any ostensible damage to the cartilaginous plates. The roentgenograms show similar defects in the vertebrae of adolescents with adolescent kyphosis.

After examining many spines of a great variety of mammals, Scheuermann concluded that "Nucleus prolapse is not seen in animals". Disc prolapses into the cartilaginous plate, spongiosa, and into the vertebral canal were observed in our older experimental animals. The prolapse of intervertebral-disc material into the spongiosa of the vertebrae occurred only after major breaks in the cartilaginous plates. At the level of the intervertebral-disc degenerations and prolapses, we always noted loose insertions of the supraspinous and interspinous ligaments. We may speculate that similar lesions develop in humans and that many "low-back strains" are perhaps due to loosening of the ligamentous insertions of the vertebral syndesmosis. Disc degenerations and prolapses may follow these defects.

Slipping and diastasis of the sacro-iliac joint were seen in many experimental animals, because of loosening of the ligamentous insertions. Similar lesions could explain sacro-iliac pain in humans.

We have not looked for the occurrence of neural-arch defects in our experimental animals, and we do not know whether or not they occur. We adhere to Roberts's idea that these defects seen in human beings are stress fractures. We may speculate that spondylolysis and spondylolisthesis develop in the lumbar spine of human beings if the

vertebral ligamentous attachments loosen. The articular processes of the lumbar vertebrae prevent the bodies from slipping forward. Because of the erect posture, a major stress should occur at the pars interarticularis. A stress fracture may occur at this site, and spondylolisthesis may then develop. Stewart's paper regarding the incidence of neural-arch defects in Alaskan natives indicates to us that these defects are possibly related to a dietary factor. (It may be of interest to note that the Eskimo's diet is known to be very low in vitamin E.)

Recurrent dislocation of the shoulder in human beings could be due to loosening of the insertions of the capsule and to the degeneration of the labrum glenoidale similar to the lesions seen in the shoulders of our experimental animals. Madelung's deformity of the wrist in adolescents could be due to loosening of the insertions of the articular disc and of the interrosseous membrane and to disturbances of the epiphyseal plate of the radius.

The pathogenesis of Legg-Perthes disease has been unknown. Microscopic studies of the upper end of the femur of one experimental animal showed a lesion similar to the Legg-Perthes disease described by Gall and Bennett. We believe that Legg-Perthes disease may be produced by a major defect in the epiphyseal plate of the upper end of the femur, with extensive rent formation which is responsible for the disruption of the retinacular vessels when they pierce the epiphyseal cartilage. New-bone formations along the borders of the femoral neck, metaphyseal defects, and premature closure of areas of the epiphyseal plate, often seen in Legg-Perthes disease, could be due to the extensive disruption of the epiphyseal plate. The pathogenesis of the so-called osteochondritis and epiphysitis in other bones is probably similar to that of Legg-Perthes disease.

Slipping of the upper femoral epiphysis occurs in fast-growing adolescents who are often overweight and who occasionally have endocrine disturbances, producing delayed closure of the epiphysis. In our experimental animals, epiphyseal slipping occurred less frequently in the upper end of the femur than in the epiphyses about the knee and the shoulder. The greatest frequency of slipping of the femoral epiphysis in human beings may be blamed on the obliquity of this epiphysis. The slipping is probably due to the weakening of the transitional zone of the epiphyseal plate similar to the lesion seen in our animals.

Infantile cortical hyperostosis is characterized by tender swellings followed by extensive formation of periosteal bone. We have studied one child with this disease, and the biopsy specimen from the involved tibia showed connective tissue and periosteal new-bone formation occurring underneath the lifted periosteum. This lesion is quite similar to the extensive periosteal new-bone formation seen in all our young experimental animals. It could be that infantile cortical hyperostosis is related to a weakening of the ground substance which binds the periosteum to the bone.

Painful partial detachments and fragmentation of the tibial tuberosity (Osgood-Schlatter disease), of the tuberosity of the os calcis, and of other sites of insertions of strong ligaments and tendons are often seen in adolescents. The nature of these lesions is perhaps similar to the detachment of the tibial tuberosity seen in our experimental animals.

It is interesting to speculate on the possible relationship between the degenerative arthritis in human patients and the degenerative arthritis seen in our experimental animals. Pathologically they are quite similar. We feel that, in the pathogenesis of degenerative arthritis in human beings, the capsular lesions which have been little studied play just as important a role as the lesions of the joint cartilage.

The possible relationship between Paget's disease in human patients and the bone lesions resembling those in Paget's disease observed in our experimental animals can be only briefly mentioned. There is need for further experimentation with larger groups of older animals. We can only say that it is possible that the underlying cause of Paget's disease may be a defect of the mucopolysaccharides present in the cement substance of bone.

Dissecting aneurysms of the aorta observed in the younger groups of experimental animals are grossly and microscopically similar to the cases of medial degeneration of the aorta seen in humans. Here again it is surmised that there is a fault of the ground substance of the media. It is of interest that of seven patients reviewed by us who died of dissecting aneurysm of the aorta, two had a severe adolescent kyphosis, three had a mild scoliosis, and one had a thoracic deformity. The spine and thorax were normal in only one patient.

SUMMARY

Diets containing *Lathyrus odoratus* seeds fed to rats produce a hitherto unrecognized lesion in the epiphyseal plates. These are very wide, the cartilage matrix appears to lose cohesion, and the cartilage cells are grouped in clusters. The same diets produce loosening and detachments of the tendinous and ligamentous insertions.

Because of these two lesions, occurring independently or together, the following skeletal conditions developed in the experimental animals: Epiphyseal slippings, metaphyseal fibrous defects, kyphoscoliosis, thoracic deformities, detachments of the tibial tuberosity, subluxations and dislocations of the shoulder, diastasis of the sacro-iliac joints, degeneration of the intervertebral discs, disc herniations, Legg-Perthes-like disease of the femoral head, and valgus of the forepaws.

In practically all the experimental rats there were extensive areas of periosteal new-bone formation following detachment of the periosteum.

Degenerative arthritis was observed in rats fed the experimental diets for several months. Two lesions developed concomitantly,—degeneration of the joint cartilage and loosening of the capsular and ligamentous insertions.

Bone lesions resembling those seen in Paget's disease were observed in small groups of older rats.

Dissecting aneurysms of the aorta and abdominal and inguinal herniae were observed in many rats. The collagen fibers appeared to be normal on electron-microscope examination.

It is surmised that all these lesions are due to defective formation or excessive destruction of the chondroitin sulphate of the ground substance.

The possible relationship between these lesions in rats and similar lesions in humans is a matter for further study.

NOTE: The author wishes to acknowledge with thanks the assistance given him by: Dr. Warren O. Nelson, Department of Anatomy, State University of Iowa, who did the study of the endocrine organs; Dr. H. W. Beams, Department of Zoology, State University of Iowa, who did the electron-microscope studies; Mr. F. W. Kent, Head of the Photographic Department, State University of Iowa, who took the photographs; and Mrs. Mary Ann Davies, technician of the Orthopaedic Department, State University of Iowa, who was most helpful in the preparation of the slides.

ADDENDUM

Since this paper was submitted for publication, Dupuy and Lee (J. Am. Pharm. Assn., **43**: 61–62, Jan. 1954) have reported the isolation from *Lathyrus pusillus* seeds of a crystalline substance which produces the skeletal lesions characteristic of lathyrism. Schilling and Strong (J. Am. Chem. Soc., **76**: 2848, May 1954) have identified the crystalline compound isolated from *Lathyrus odoratus* as β-(γ-L-glutamyl)- aminopropiononitrile. Working in conjunction with S. Wawzonek of the Department of Organic Chemistry of this University, we have found that a diet containing 0.1 per cent. of β-aminopropiononitrile produces severe skeletal lesions. On the other hand, a diet containing 1 or 2 per cent. of propiononitrile produces no skeletal changes. We have also found that the following diets do not produce the skeletal lesions: 1 per cent. β-alanine together with 1 per cent. L-glutamic acid, 1 and 2 per cent. acetonitrile, 1 per cent. indolacetonitrile, and 0.4 per cent. of tri (β-cyano ethyl) amine. It appears, then, that β-aminopropiononitrile is the active principle contained in the lathyrus peas which produces the skeletal changes.

Working with C. Y. Chang and E. Witschi, we have found that in *Xenopus laevis* larvae fed sweet-pea seed dislocations of the joints of the hind legs and loosening of the septi of the metameres of the dorsal musculature developed. When given at a critical period, about ten days before metamorphosis, β-aminopropiononitrile, at a concentration of 1 to 500,000, produces the lesions within a week. Since the *Xenopus laevis* larva is so sensitive, it may be used in the bio-assay of small amounts of β-aminopropiononitrile. This work will be published in the Anatomical Record.

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DISCUSSION

Prognostic Implications of Electromyography

(*Continued from page 1030*)

Dr. Buchthal (closing): Thank you very much, Dr. Green, for your kind words on my deceased colleague, Helge Hertz. It was a great pleasure for all of us to work in the Children's Hospital.

If I have avoided speaking on the pathophysiological basis of the electromyographic changes in poliomyelitis, it is because such a discussion would still include a great deal of speculation. However, I can say that the increase in mean action-potential duration observed in certain paretic muscles seems to be due to an increase in the size of the motor unit. This might be caused by the peripheral branching of the surviving nerve fibers; this, however, does not seem likely, since the electromyographic changes occur at an early stage of the disease. Another possible explanation is that the disease process causes synchronous discharges of anterior horn cells; possibly their membranes are altered so that electrical processes in active cells facilitate discharges in adjacent cells. The synchronism in discharges of several anterior horn cells manifests itself in the periphery, as would an increase in the number of fibers per motor unit.

I am glad that Dr. Green drew attention to the care necessary in the clinical evaluation of electromyographic findings and to the need for critical treatment of these findings. In order to be at all reliable, electromyography must include the sampling of a number of different places in a muscle. Certainly, in the Neurological Department with which I am connected, we consider this form of examination as a necessity in diseases of the motor system.

As for the question Dr. Key raised about the correlation of electromyographic findings with the pathogenesis, we must realize that the electrical potentials we record are produced by surviving motor units, with the exception of fibrillation potentials. It is likely that the muscles in which paresis is due to oedema are those in which the activated units show normal duration in their electrical responses. Unfortunately there is no good correlation between the electromyogram and the prognosis in peripheral-nerve paresis, such as a "Saturday-night" paresis.

As to the temperature change in affected muscles in poliomyelitis, I would agree that this is due to changes in sympathetic innervation.

MATERIAL FAILURES IN HIP PROSTHESES

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The introduction of the replacement prosthesis as a method of treating diseases and injuries to the hip has been an intriguing advance in orthopaedic surgery. A thorough study of ten cases in which acrylic or nylon prostheses of the Judet type had been used will be discussed with emphasis on the inadequacies of the materials only. The indications for replacing the femoral head were not considered radical, except possibly in the case of a thirty-year-old male who had shown changes in the femoral head secondary to a fracture-dislocation of the hip ten years earlier. In the remaining nine patients, individuals over fifty years of age, nylon or acrylic prostheses had been used in the treatment of fresh fractures, non-union of old fractures of the femoral neck, and hip-joint diseases not associated directly with fractures of the hip.

Each of these cases presented a definite failure of materials, requiring secondary operations. No failure of surgical technique and no complication, such as dislocation or infection, had occurred in these individuals. The failure of the materials was indicated either by fracture, deterioration from friction, or erosion of the prosthesis by body fluids, or by an unfavorable soft-tissue reaction.

Acrylic materials had fractured in three instances. The stem had become detached from the head portion of the prosthesis in two patients, and in the third there was fragmentation of portions of the stem and the rim of the head section. In the patients in whom the head and stem sections had separated, the signs and symptoms were not unlike those noted in fresh fractures of the femoral neck. One patient had been aware of the fracture of the prosthesis when she fell from a stepladder, and the second patient had "felt something give way" when he sat heavily in a deep easy chair. The third acrylic prosthesis, which had been causing pain, was found to show multiple points of fragmentation of both the stem and the head when examined after reoperation. Small cracks could be seen through the deeper portions of the acrylic head in tangential lighting.

The fourth patient with an acrylic prosthesis had been reoperated upon because of constant pain and instability of the hip. The surface of the acrylic head portion was found to be marked by several areas of erosion suggestive of changes caused by wear and tear.

In these patients, the soft tissues adjacent to the acrylic showed a moderately vascular fibrous stroma, with little other evidence of an irritative response to this foreign substance. The gross appearance of this tissue was not unlike that of the lining of a normal bursa, with a smooth glistening surface and a pale pink color. Fragments of acrylic, phagocytic reaction, and giant-cell production were absent in these patients; these findings differ from those regarding polythene, as reported by Newman and Scales[1].

Six cases in which a nylon prosthesis had been used have been studied. In each, a second operation had been necessary, because of persistent pain of a degree sufficient to prohibit comfort at rest as well as during limited activity while supported by canes or crutches. Limited motion, hip adduction, and muscle spasm were present in all of these patients. One woman of sixty-three years complained that the hip seemed to "come out of place" on certain motions of the extremity. When the joint had been exposed at surgery, a definite cleft of erosion in the head portion of the prosthesis was noted (Fig. 2-A). This cleft was located in such a manner that it became caught upon the rim of the acetabulum in flexion. Any motion that continued in this particular direction produced an incomplete subluxation which continued until the prosthesis had been released and, with an audible snap, had resumed its position in the acetabulum.

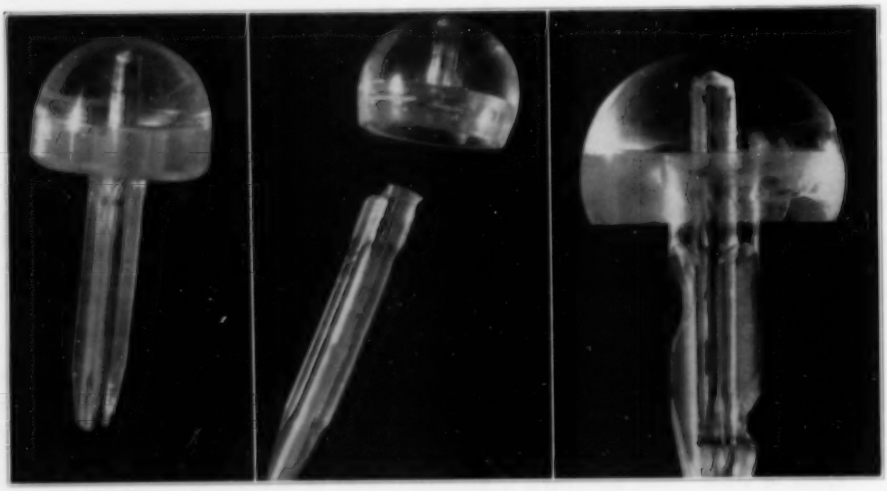

FIG. 1

Three acrylic prostheses, showing surface erosion of the head portion in the first view and fractures of the material in the other two.

The nylon prostheses removed from the remaining five patients in this group revealed some degree of surface change over the head portion. Three prostheses showed smooth shallow cavities suggestive of an erosion process by body fluids (Figs. 2-B and 2-C). The others were marred by distinct areas of irregularity similar to the sharp furrows which might result from the use of a file or power tool. The gloss was absent in all the areas where particles of the nylon substance had disappeared, regardless of the suspected destructive factor involved. The stem portion of two prostheses and a nylon washer used upon another

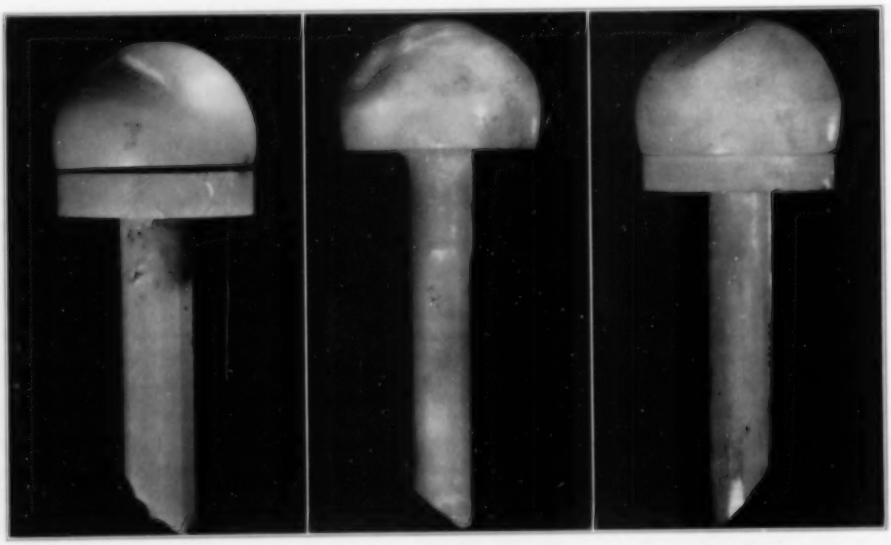

FIG. 2-A FIG. 2-B FIG. 2-C

Fig. 2-A: Note sharp cleft in head surface of nylon prosthesis and small pits in stem portion.
Figs. 2-B and 2-C: Erosion or friction is suggested as the destructive factor in these nylon prostheses.

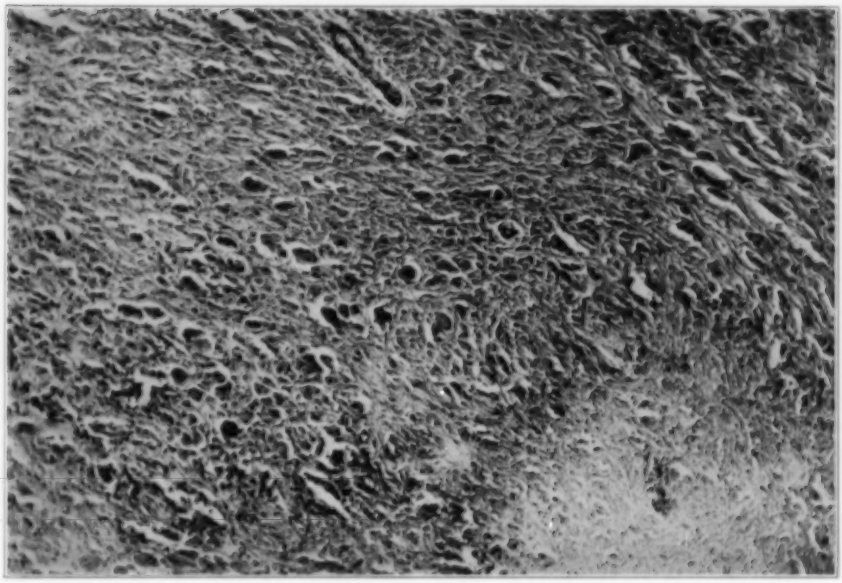

FIG. 3

Photomicrograph (× 70), showing large number of giant cells in a loose fibrous stroma with absence of nylon fragments. Lower right-hand area shows necrosis.

were found to have numerous pits, some as deep as one millimeter. These changes appear to be secondary to chemical change rather than physical or friction phenomena. Both chemical and physical factors appear to have been active in these cases.

In all six individuals, copious amounts of a yellowish granulation tissue surrounded the stem and filled the capsular space. This tissue was also abundant in the acetabulum except in areas of close contact between the prosthesis and the opposing acetabular surface. The tissue was of a firm consistency and bled only moderately when traumatized with a scalpel. In all instances, such tissue was removed as completely as possible.

Histological sections of this tissue revealed a fairly uniform pattern in all cases. The stroma was a loosely arranged fibrous tissue showing moderate numbers of small vascular channels and widespread giant cells. These giant cells varied widely in size, and in the number of nuclei and amount of cytoplasm which they contained.

Numerous fragments of nylon were noted throughout all of the sections in five cases and were sparse and smaller in the sixth case (Figs. 3 and 4). The particles of nylon were irregular and sometimes fibrillar. Nylon is opaque, and its staining qualities have not been learned. There was a striking absence of phagocytes about the particles of nylon in all six cases. The giant cells were not located near the foreign bodies. The surface of the granulation tissue which lay near the prosthesis was seen to have numerous particles of nylon attached (Fig. 4).

Various stains were used but these failed to add any specific information not noted in the specimens stained with hematoxylin and eosin. Capillary stains did accentuate the vast network of the small blood channels throughout all sections.

The tissue reaction to nylon in these patients was very definite, in sharp contrast to the paucity of tissue changes seen in patients in whom acrylic or stainless-steel prostheses have been used and exposed to the same factors. The tissue reaction produced by such a substance as nylon appears to have been increased by the introduction into the tissue of numerous free particles of nylon by erosion or friction. The production of numerous frag-

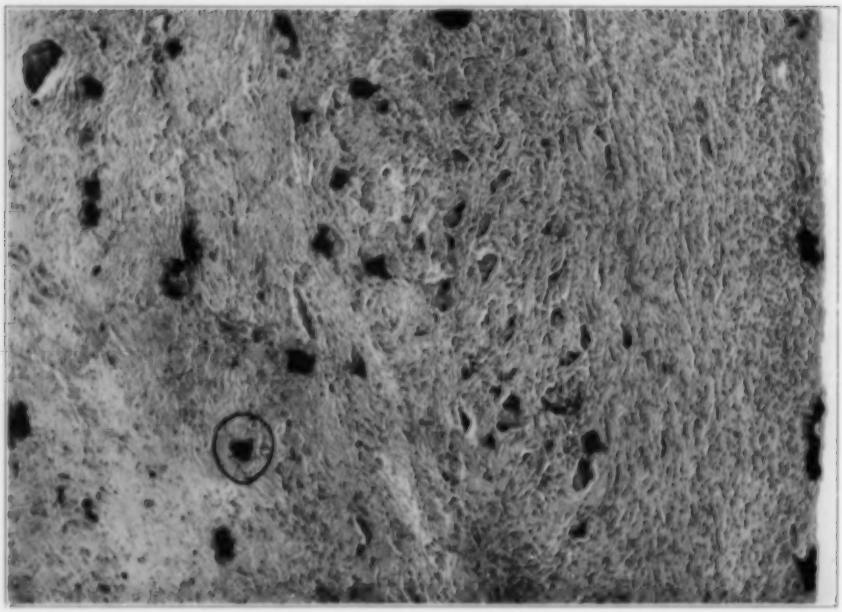

FIG. 4

Photomicrograph (×70) of a section through a nodule of granulation tissue which was adjacent to nylon material in a hip joint. Note large dark masses of nylon (circle), giant cells, absence of phagocytic reaction about foreign bodies, and the newly incorporated nylon fragments in the surface of the nodule as seen on the right.

ments increases the exposed surface area. In this situation, motion is probably a factor, since it tends to wear down or to fragment the exposed surface. It is to be noted that none of these individuals had shown dermal reaction to either nylon clothing or patch tests of the prosthesis material.

In summary, ten cases of materials failure have been observed in hip prostheses. Acrylic and nylon do not appear to have all the qualities necessary to make their use wholly justified in hip surgery at this time. Experimental work must be carried out to fully clarify the entire problem. We feel that the findings presented show the need of a thorough study. Nine of these ten patients have been treated secondarily with a metal, intramedullary type of prosthesis and one by arthrodesis of the hip.

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END-RESULT STUDY OF SIXTY-TWO STAPLING OPERATIONS *

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The problem of limb-length discrepancy is a major concern in every large orthopaedic clinic. At the Orthopaedic Hospital in Los Angeles, 110 limb-lengthening operations, thirty-five limb-shortening operations, twenty-two epiphyseal stimulations, 162 epiphysiodeses, and sixty-two stapling operations have been done. This last figure does not take into account staplings of the fibular epiphysis which may have been done in connection with stapling of the tibial epiphysis.

When Blount and Clarke, in 1949, first described epiphyseal stapling to control growth, we became interested in this procedure. It seemed a simpler and a safer operation than epiphysiodesis. Best of all, it seemed to eliminate the uncertainty in the calculation of expected future growth of the extremities.

THEORETICAL CONSIDERATIONS

Epiphyseal stapling, however, poses certain potential problems, the answers to which can be resolved only by time and experience.

In view of the apparent tremendous growth force associated with the epiphyses at the ends of long bones, it was wondered if stapling could effectively retard growth. Also, it was necessary to know whether or not staples left in place for two years would sufficiently improve a discrepancy in limb length to make the procedure worth while.

The procedure seemed to have one inherent weakness—a weakness which had in the past been encountered in limb-lengthening operations. With the latter procedure, a gain of five centimeters in added length, particularly in the poliomyelitic patient, could be consistently gained. Following the procedure, limb lengths remained the same for a varying period of time. Later, however, when spurts of growth occurred, the discrepancy in limb length re-asserted itself. This of course took place in those patients in whom the growth potential of the two extremities was different. Instances of this were found in patients with poliomyelitis in whom one extremity was involved or in whom one extremity was involved to a greater extent than the other, in patients with congenitally short lower extremities in whom there was often increasing discrepancy with growth, and in patients with limbs in which through disease or trauma an epiphysis had been destroyed. There seemed to be no reason to assume that the stapling operation would not have this same disadvantage if the epiphysis had not been injured by the stapling.

At the time the authors began to do epiphyseal stapling, there was not enough evidence collected to assure them, beyond all doubt, of what would happen to the growth of the extremity operated upon when the staples were removed two years later. Because of this uncertainty, the first patients were selected from an older age group. In this way, it was hoped to avoid the possible tragedy of premature closure of an epiphysis in the normal limb of a young child. In fact, the majority of the patients operated upon to the present have been about ten or eleven years old. This, of course, has a disadvantage. When the staples are taken out two years after operation, there is not usually enough of the growth period remaining to obtain information regarding the effect of stapling on growth after the staples have been removed. On the other hand, the operation does have the advantage that the staples are in place during a period of relatively rapid growth;

*Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 28, 1954.

thus more information, possibly, can be gained as to the effectiveness of the stapling during the period in which the staples are in place. Another advantage is that the limb-length discrepancy remains more nearly stabilized if growth is near completion.

In general, the technique described by Blount and his associates has been followed. This series has not been large enough nor has sufficient time elapsed to gain all the information for which the authors had hoped.

POTENTIAL HAZARDS

There are potential hazards connected with any surgical procedure about the epiphysis, whether it be epiphysiodesis, epiphyseal stimulation, or stapling. For instance, in epiphyseal stimulations, the authors have noted the following complications: More stimulation of bone growth occurred if the screw or ivory peg had been placed in close proximity to the epiphyseal line. If the screw had been inadvertently placed somewhat obliquely so that one end of the screw was closer to the epiphyseal line than the opposite end, there followed, in a few instances, an angular deformity. On one occasion, when the periosteum had been incised and had been reflected preparatory to the introduction of the screw, a bony bridge formed across the epiphyseal line which amounted to a unilateral epiphysiodesis. This resulted in marked angular deformity and further shortening of an already short extremity.

This complication might well occur in a stapling operation if the periosteum is stripped back and the staple is placed subperiosteally. The complication has, in fact, occurred and will be mentioned later.

LIMB-LENGTH DISCREPANCIES

1. *General Information*

In forty-two patients, fifty epiphyses were stapled. There were thirty-two stapling procedures done on the distal femoral epiphysis and eighteen on the proximal tibial and fibular epiphyses. In three instances, both femoral and tibial epiphyses were stapled at the same time.

The average age of the forty-two patients was ten years and eight months; the youngest patient was seven years and three months old.

Twenty-nine of the patients were males and thirteen were females.

The limb-length discrepancy in the forty-two patients was due to poliomyelitis in nineteen, trauma in eight, congenitally short lower extremity in ten, cerebral palsy in one, osteomyelitis in one, Legg-Perthes disease in one, and arteriovenous fistulae in two.

2. *Specific Information*

A. *Extrusion of staples:* In six patients in whom the staples had been placed extraperiosteally, there was considerable spreading and extrusion of the staples. This was seen on the roentgenograms in from two to eight months. The staples were replaced in these six patients. There was no direct evidence later that replacement of the staples caused epiphyseal damage. There were nine other patients in whom there was extrusion of the staples to a lesser degree; in these, the staples were not replaced.

B. *Improvement in leg-length discrepancy:* The average time the staples remained in place was two years and twelve days. The longest time was four years. The average limb-length discrepancy at the time of surgery was 3.1 centimeters. The average limb-length discrepancy after the staples had been removed was 2.2 centimeters. The average linear growth of the stapled femur while the staples were in place was 2.2 centimeters, compared with a growth of 3.4 centimeters in the unstapled femur. The average linear growth of the stapled tibia was 2.8 centimeters, compared with 3.1 centimeters in the unstapled tibia. If the stapling operation had not been done, the limb-length discrepancy during this two-year period would have shown a gradual increase instead of a decrease of 0.9 centi-

meter. Part of this decrease in discrepancy, however, disappears after the staples have been removed. If the two extremities have a different growth potential, the longer extremity will, after the staples have been removed, again grow faster than the short extremity. How much faster the normal extremity will grow than the short one will depend upon the years of growth remaining after the staples have been removed. In only one patient were the limbs of equal length when the staples were removed.

C. *Premature epiphyseal closure:* In six patients there was a premature epiphyseal closure. Five of these were in the early patients in whom the staples had been placed subperiosteally. Fortunately, the patients were in the older age group and, except in one patient, epiphyseal closure did not result in too much shortening in the extremity operated upon.

D. *Broken staples:* There were seven broken staples in three patients. In the first patient, roentgenograms showed one broken staple thirty-four months following surgery, and six months later, a second staple broke. In the second patient, one staple broke at fourteen months, and over the following fifteen months, three more staples broke. In the third patient, one staple broke at seventeen months.

E. *Bone and metal reaction:* In no instance was there any erosion of the staples nor was there any bone reaction about the staples.

F. *Deformities:* There were four bow-leg deformities and one knock-knee deformity of significance; one of the former was caused by broken staples. In eight patients, back-knee deformity developed.

1. *Back-knee deformities:* In eight patients, there developed significant back-knee deformity. Two of these, however, were in the group of patients who had knock knees originally. In each of these, it was felt that the pre-existing multiple osteochondroma and an injured proximal tibial epiphysis probably caused the back-knee deformity rather than the stapling operation itself. In the six patients with back-knee deformities in the group of patients with limb-length discrepancies, there was back-knee deformity ranging from 10 to 27 degrees. In four of these patients, the epiphysis of the tibia had been stapled; in one the epiphyses of the femur and tibia had been stapled; and in one the epiphysis of the femur had been stapled. Back-knee deformities are probably caused, in part at least, by the difficulty of placing the staples posteriorly; this is especially true in the tibia. More careful attention to the placing of the posterior staples should reduce the incidence of this complicating deformity.

2. *Bow-leg deformities:* In four patients bow-leg deformities developed. In three of these patients, the tibial epiphysis had been stapled; and in one both the tibial and femoral epiphyses had been stapled. This deformity is probably caused by the greater flare of the lateral tuberosity of the tibia as compared with that of the medial tuberosity. This frequently meant that the distal arm of the staple on the lateral side of the tibia was not so well embedded as were staples which had been placed on the medial border. Three of these patients were subjected to an osteotomy in order to correct the varus deformity which had developed.

G. *Growth after removal of staples:* The information available on the basis of this series is too meager to allow definite conclusions to be drawn. This is due in part to the fact that many of the patients were near the end of their growth when the staples were removed, and sufficient time has not elapsed in the other patients in whom the staples had been removed at a younger age. However, there were ten patients from whose histories some information can be gained (Table I). In a few, the unstapled slower-growing extremity grew as fast as or faster than the stapled extremity after the removal of the staples, while in others the reverse was true. The average age at which staples were removed was 11.8 years. The average time the staples were in place was 22.7 months, the longest being forty-four months. The average follow-up time after removal of the staples was 13.2 months, the longest period being thirty-seven months. In eight of the ten cases, the stapled

TABLE I

GROWTH AFTER REMOVAL OF STAPLES IN GROUP OF PATIENTS WITH LIMB-LENGTH DISCREPANCIES

Diagnosis	Sex	Age Staples Removed	Site	Staples in Place (*Months*)	Follow-up Period (*Months*)	Epiphysis Re-opened (*Seen by X-Ray*)	Growth in Stapled Bone (*Centimeters*)	Growth in Unstapled Bone (*Centimeters*)
Poliomyelitis	M	12 yrs., 5 mos.	Femur	9	6	Yes	0.6	0.6
Cerebral palsy	M	9 yrs., 7 mos.	Femur	15	37	Yes	6.6	7.2
Legg-Perthes disease	M	14 yrs., 6 mos.	Femur	28	6	Yes	0.6	1.3
Poliomyelitis	M	13 yrs., 11 mos.	Femur	30	17	No	0.9	2.5
Arteriovenous fistulae	M	12 yrs., 3 mos.	Femur, tibia, and fibula	44 (Staples buried in bone)	6	Yes	3.4	3.1
Congenitally short extremity	M	13 yrs., 4 mos.	Tibia and fibula	26 (Staples buried in bone)	6	?	0.9	0.6
Congenitally short extremity	F	10 yrs., 6 mos.	Tibia and fibula	20	6	Yes	0.6	0.3
Poliomyelitis	M	8 yrs., 6 mos.	Femur	9	11	Yes	1.6	1.6
Congenitally short extremity	M	12 yrs., 8 mos.	Tibia and fibula	22	10	Yes	2.5	0.6
Congenitally short extremity	M	11 yrs., 11 mos.	Femur	24 (Staples buried in bone)	27	Yes	4.7	1.9

TABLE II

KNOCK-KNEE DEFORMITY

Diagnosis	Age	Staples in Place		Preoperative Deformity				Postoperative Deformity				Later Measurements			
				Knock-Knee		Back-Knee		Knock-Knee		Back-Knee		Knock-Knee		Back-Knee	
		Femur (*Mos.*)	Tibia (*Mos.*)	Right (*Degrees*)	Left (*Degrees*)	Right (*Degrees*)	Left (*Degrees*)	Right (*Degrees*)	Left (*Degrees*)	Right (*Degrees*)	Left (*Degrees*)	Right (*Degrees*)	Left (*Degrees*)	Right (*Degrees*)	Left (*Degrees*)
Vitamin-D-resistant rickets	10 yrs., 6 mos.	12		20	25			7	10						
Uncomplicated knock-knee	13 yrs., 3 mos.	3½		11	10			1	2			5 (3 yrs. later)	5		
Poliomyelitis	13 yrs., 3 mos.	26		14				7							
Congenital pseudarthrosis with below-the-knee amputation	7 yrs., 3 mos.	16		15				10							
Fractured proximal tibial epiphysis	12 yrs., 8 mos.		27	10	7	10	7	16	9	14	0				
		(The poor results on the right are probably due to preoperative condition.)													
Multiple osteochondroma	12 yrs., 4 mos.		14	20	15	5	5	6	6	0	0	3	1	19 (16 mos. later)	20
		(Postoperative back-knee deformity probably due to preoperative condition.)													
Uncomplicated knock-knee	8 yrs., 6 mos.	9		25	25	0	0	4	2	0	0	4	0	9 (19 mos. later)	10
		(Staples in right extremity were easily removed; those in left extremity were removed with difficulty. Both limbs grew at equal rate for 19 months after the staples had been removed.)													

epiphyses re-opened as seen by roentgenograms. One did not re-open, and one was questionable; in this last case, the stapled bone grew as much as the unstapled bone after the removal of the staples. During the average time of 13.2 months following removal of the staples, both the stapled bone and the corresponding unstapled bone grew 1.9 centimeters. In three of these cases, the staples when removed were buried in bone. The staples in these patients had been in place for forty-four, twenty-six, and twenty-four months, respectively. In spite of this, after the staples had been removed, the stapled bone grew at least as fast as the corresponding unstapled bone in the 9.4 months during which they were observed.

KNOCK-KNEE DEFORMITY

In seven patients, epiphyseal staplings were done for knock-knee deformity. Five staplings were done bilaterally and two unilaterally (Table II).

In five patients, the distal femoral epiphysis was stapled on the medial side and in two patients, the stapling was done on the medial side of the proximal tibial epiphysis.

The average age of the patients was eleven years. The average time the staples were left in place was sixteen months, the shortest time being three and one-half months and the longest twenty-seven months.

In the twelve extremities operated upon, there was an average knock-knee deformity of 16.5 degrees. This was reduced to 5.5 degrees. This latter figure does not take into consideration the patient in whom the deformity became worse. This patient had suffered trauma to and deformity of the proximal tibial epiphysis. It was felt that this presurgical condition was responsible for the poor result rather than the stapling. In another patient who had multiple osteochondroma of the lower extremities a significant back-knee deformity developed which was probably not due to the stapling. There was, however, one patient, eight and one-half years old, with bilateral uncomplicated knock-knee deformity of 25 degrees who had had no preoperative back-knee deformity. The staples had been in place for nine months; during that time no back-knee deformity was present. The knock-knee deformity was unusually well corrected. In the following nineteen months after removal, the limbs grew equally, the knock-knee deformity remained well corrected, but a 10-degree back-knee deformity developed. There was nothing to be seen on the roentgenograms to account for this complication.

UNCERTAINTY OF RESULTS

There were ten instances of buried staples. Most, but not all, occurred because the staples had been placed subperiosteally. In some instances this resulted in permanent epiphyseal arrest; in others, the epiphysis re-opened and linear growth proceeded normally, or almost so, after the staples had been removed. In one patient growth was resumed after the staples had remained in place forty-four months.

In most patients, the equalizing of limb-length discrepancy was disappointing, and, for this reason, stapling was followed by epiphysiodesis in sixteen patients (33 per cent.).

In some patients, the stapling caused very little growth retardation in a two-year period; in others, an appreciable improvement in the discrepancy was noted. The explanation for this may be found, in part, in the fact that there had been a varying degree of extrusion of the staples. In six patients, there had been considerable extrusion, and replacement was done in these patients. In one, three staples had been completely extruded. Perhaps more of the partially extruded staples should have been replaced. However, partial extrusion of a staple does not always explain the poor results. In some patients in whom there had been little or no extrusion, very little improvement in the limb-length discrepancy was noted. In the patient in whom the staples were in place for four years, the limb-length discrepancy was reduced from 6.6 centimeters to 4.4 centimeters. However, in some instances where roentgenograms showed partial extrusion of staples, effective epiphyseal arrest occurred.

SUMMARY AND CONCLUSIONS

Sixty-two epiphyses in forty-nine patients were stapled. Seven patients were subjected to stapling for knock-knee deformity and forty-two for limb-length discrepancy.

Limb-Length Discrepancy

The improvement in limb-length discrepancy was disappointing. Frequently in a two-year period, the two limbs grew at about the same rate. From a study of growth charts, it was determined that one cannot expect correction of a major discrepancy in limb lengths in a two-year period. This is especially true if only one epiphysis is stapled or if the patient is not growing rapidly during the time the staples are in place.

It became apparent that some of the gain obtained by the stapling was later lost during a period of rapid growth. Enough time has not elapsed for this point to be made with certainty.

Partial extrusion of staples was fairly common. Perhaps the results would have been better if more of the partially extruded staples had been replaced. This means that the patient must undergo a second operation and finally a third operation when the staples are removed.

In sixteen patients (33 per cent.) epiphysiodesis was done after the staples had been removed because of residual major discrepancy.

Staples buried in bone were a common finding, especially when the staples had been placed subperiosteally. There were six cases of epiphyseal arrest, in five of which the staples had been placed subperiosteally. In three, however, linear growth continued normally in spite of this complication, after the staples had been removed. Nevertheless, buried staples are a hazard in patients in the younger age group.

Back-knee deformities as a postoperative complication were too common. These might be avoided by more careful attention to the placing of the staples in the posterior aspect of the tibial epiphysis.

In general, the limited data available indicates that linear growth continues normally or almost so, after staples have been removed, excluding, of course, cases of epiphyseal arrest.

Knock-Knee Deformity

The results in patients with knock-knee deformity were better. Most patients were improved. However, in two patients a significant back-knee deformity developed, but in both instances this was probably due to the preoperative condition.

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DISCUSSION

Dr. Walter P. Blount, Milwaukee, Wisconsin: I congratulate Dr. Brockway and his associates upon presenting a dispassionate and frank review of the various complications of the stapling operation. In papers and personal communications, I have warned against the errors in technique which cause these unfavorable results. I have told how to prevent these complications, and how to correct them if they are permitted to occur.

The first requisite is to place the staples properly. Accurate anteroposterior and lateral roentgenograms made in the operating room must prove that the staples have been exactly inserted. When one drives one staple in, care must be taken not to drive another out. All staples should be inspected before the wounds are closed. If a staple is slanting so that one corner protrudes, it will probably pull out. A frequent mistake is to let one leg of a staple placed posteriorly slide along the cortex of the bone instead of penetrating the bone squarely. This can be avoided if the staple is aimed toward the center of the bone. Flexion of the knee facilitates proper aiming. The anterior third of the fibula should be cut away in order to expose the posterior portion of the tibia on the lateral side. After the epiphyseal plate of the fibula has been curetted, the loose piece should be replaced. These are important technical details; poor technique causes complications.

Dr. Brockway and his associates had inadvertent epiphyseal fusion not only with stapling but also with bone stimulation. This accident should *not* happen. One must not damage the epiphyseal plate. Staples are inserted *through* the periosteum, not *under* it, in order that they may be easily removed later. It is the removal, not the insertion, of staples which is likely to injure the epiphyseal cartilage; it is trauma, not time, which causes premature closure. As has been stated, we know now that *four* years of stapling during a period of rapid growth will not cause permanent arrest. On the contrary, in the first few weeks after the staples have been removed, the cartilaginous plate, which has been so paper-thin as to frighten the inexperienced surgeon, expands rapidly to almost twice its normal width. Growth of this epiphysis is temporarily accelerated.

It is amazing to what degree of trauma a healthy epiphyseal plate may be subjected and still resume growth; however, one must not tempt Providence too far. In our patients the most significant errors were made by overenthusiastic house officers. In one patient, there was bowing following removal of a biopsy specimen from the epiphysis. In almost 200 stapling operations, we have had one other bow-leg deformity, four knock-knee deformities, and two back-knee deformities. One patient required no treatment; osteotomy was necessary in one. The osteotomy was done because the limbs were of equal length. In most cases, stapling had been done on the long limb. If faulty placing of staples or later extrusion caused deformity, it was recognized early and was corrected by rearrangement of the staples. There was then no need for osteotomy. Accurate re-insertion of staples is easy when the new staple is driven in before the old one is withdrawn. The periosteal soft parts are cut down to the bone after the staple has been driven in.

If I had time I should challenge many of the *indications* for operation in the series just presented. I have always said, "Do not staple children under eight". Many surgeons have ignored this advice. At Phemister's suggestion I first said that I could not be sure of the resumption of growth following removal of staples which had been left in longer than two years. Dr. Brockway and his associates have overemphasized the discarded two-year limit. Most men have left them in as long as necessary. We cannot measure the effectiveness of the staples in terms of time. It is a question of how much growth takes place in the other limb while staples are *in situ*. Two years may be long enough to correct a two-inch limb-length discrepancy. In another case, two years may not allow *any* correction if growth in the limbs has been minimal.

I say again that Dr. Brockway and his associates have done a real service in pointing out errors which have been made. In all fairness, however, the title of their paper should have been, "Technical Errors Which We Have Made in the Stapling Operation".

Dr. Charles H. Frantz, Grand Rapids, Michigan: Dr. Brockway and his associates have presented a very interesting analysis of their results from stapling operations. This procedure is an exacting one and one not to be taken lightly. The complications encountered are similar to those we encountered early in our series.

As of September 1953, we had performed ninety-three stapling operations. Of these, eighty-five were attempts to correct linear-growth discrepancies; five limbs were stapled above and below the knee. Twenty-five of these children have had their staples removed and are now being followed carefully by means of clinical and roentgenographic measurement. The staples remained *in situ* for an average of two years and seven months; the average age at the removal of the staples was thirteen years and two months. The longest period any of the staples have remained in place in any child is four years and two months.

It would appear to me that Dr. Brockway's disappointment is due to man-made errors. The first, and many of us have committed it, is raising a periosteal flap for the exposure of the epiphyseal line. This is unnecessary; it leads to buried staples, the removal of which is most difficult and traumatizing.

Dr. Brockway reports one knock-knee, four bow-leg, and eight back-knee deformities. This is a high incidence of subsequent growth complications and, in the light of our experience, is due to man-made error. We have had two cases of knock-knee deformity, two cases of bow-leg deformity, and one mild knee-flexion deformity. On critical analysis, we think these complications have been due to poor placement of the staples.

Staples must be placed symmetrically in order to correct a limb-length discrepancy. The epiphyseal line is identified by needling and checking with a scout film. By means of palpation anteriorly and posteriorly, the first staple can be place in the mid-coronal plane. The anterior and posterior staples are then placed 0.6 centimeter from it. The staples should be in the same vertical plane; they should not vary in distance from the epiphyseal line. They should *not* be buried but be clearly visible, firmly hugging the cartilage. The placement must be checked by x-ray. This operating-room exposure should be carefully positioned to minimize distortion.

Dr. Brockway reports fracture of seven staples in three patients. This complication occurred in one staple in our series. We are completely dependent upon manufacturers and surgical supply houses for our metal. At present the products seem to meet the requirements, but there is room for improvement.

Our statistics on the diminishing of limb-length discrepancy have been much more encouraging than Dr. Brockway's. We have been able to equalize discrepancies of 3.1 centimeters. If there is *little* limb growth while the staples are *in situ*, naturally, there will be very little correction. Leave the staples in *longer*.

Clinical measurements should be checked with x-ray measurements of bone lengths. When metallic

(Continued on page 1081)

THE PROBLEM OF REFRACTURE IN FRACTURES OF THE FEMORAL SHAFT

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Fractures of the shaft of the femur present a serious economic problem in hospitalization and cost of medical care. There is also the factor of subsequent disability due chiefly to the effects of prolonged immobilization. Intramedullary nailing, when indicated and properly applied, has greatly reduced the economic burden, the time of hospitalization, and the residual disability. However, many patients who have femoral fractures which are not suitable for nailing still require treatment by traction-suspension with its long period of recumbency and immobilization.

Any additional factor which is superimposed on the already great economic burden may well be a severe hardship to the patient and may further decrease his functional recovery. Refracture in the area of the femoral-shaft fracture is such a factor and causes a tremendous increase in the period of hospitalization, financial cost, and degree of disability. It would seem worth while to investigate the causes of such refractures, in order to establish, if possible, the ways and means to prevent such incidents. Although the problem of refracture is mentioned by most authors on the subject of the management of femoral-shaft fractures, there is little information in the literature concerning the incidence, the etiology, the treatment, or the increase in residual disability associated with this complication.

Refracture should be defined and distinguished from delayed union and non-union. The term should be reserved for new breaks in the area of those fractures which had been considered to be clinically solid and which had presented the roentgenographic appearance of satisfactory bony union. Complete disappearance of the fracture line on the roentgenogram is not a requirement, but there should have been evidence of bone-bridging of the fracture gap and absence of changes suggesting delayed union or non-union. Under such circumstances, and following the removal of the immobilization apparatus, if there is clinical and roentgenographic evidence of a new break in bone continuity at the old fracture site, the condition is considered to be a refracture. This usually occurs as the result of a definite injury, but the trauma may be so slight that formal injury is denied. It is our purpose to determine, if possible, the circumstances under which these refractures occur, since a considerable proportion would appear to be avoidable.

The present study includes a group of 132 patients who had presented 135 fractures of the femoral shaft. All of these patients had completed their treatment in an Army general hospital, although some of them had originally been treated temporarily in other institutions. All of them have been observed for a period of time sufficient for evaluation of the important aspects of the treatment, the factors which might have affected the incidence of refracture, and the functional end results. The group represents the number treated in a three-year period without any attempt at selection.

STATISTICAL ANALYSIS

In the group of patients with 135 femoral-shaft fractures treated by us, twelve (8.9 per cent.) presented evidence of refracture following discontinuation of the immobilization. For the purpose of studying the factors involved in refracture, we have also included six patients who had come to us in the convalescent stage after completion of immobilization. These patients sustained refractures while undergoing rehabilitation,

TABLE I

COMPARISON OF FUNCTIONAL RECOVERY OF FRACTURES OF THE FEMORAL SHAFT WITHOUT ASSOCIATED INJURY

	Original Injury		Refracture
	Results after Treatment by Intramedullary Nailing	Results after Treatment by Traction-Suspension or Plaster Fixation	Results after Treatment
No. of patients	24	25	14
Average time before full ambulation (weeks)	9.5	25.5	48.5
Average time of hospitalization (weeks)	16.0	28.9	63.6
Recovery of knee motion (No. of patients)			
Normal	17	5	1
Flexion greater than 90 degrees	7	15	6
Flexion less than 90 degrees	0	5	7
Limitation of extension	0	2	0
No. of patients with shortening in excess of one inch	1	5	7
Disposition			
Return to full duty	6	9	0
Return to limited duty	18	12	4
Unfit for duty	0	4	10
Additional complications			
Pulmonary	0	0	0
Renal	0	0	2
Mental	0	0	5
Gluteal atrophy	0	0	1

and their subsequent management was carried out by us. With these additional patients, we have a series of eighteen case histories of femoral refractures for analysis and interpretation.

Original Fracture

Type of original fracture: There were six refractures in patients whose original fractures had been closed and twelve in patients whose original fractures had been open. Ten of the latter were due to missile wounds. All of the refractures were of the closed type. The ages of the patients with refractures were from seventeen to forty-two years. Eleven patients were under the age of twenty-five.

The mid-shaft of the femur had been the original fracture site in eleven cases. Four of the original fractures had occurred in the upper third of the shaft and three in the distal third. A severe bursting type of fracture had occurred in eight patients with marked shattering of bone. The fractures had been transverse or oblique in six patients; and, in four patients, of the butterfly-fragment type.

Type of initial treatment: Fourteen patients who subsequently presented refractures had been treated originally by traction-suspension. In three, intramedullary-nailing procedures had been performed, two of which had been through septic areas with the wounds left wide open for drainage. One patient had been treated by immobilization in plaster.

FIG. 1-A

FIG. 1-B

Fig. 1-A: Lateral roentgenogram of fractured femur six months after fixation by intramedullary nail and three wire loops. Nail had been removed because of appearance of electrolytic bone absorption. (Courtesy of Letterman General Hospital Photographic Laboratory.)

Fig. 1-B: Similar view two weeks later, showing refracture and angulation. (Courtesy of Letterman General Hospital Photographic Laboratory.)

FIG. 2-A

FIG. 2-B

Anteroposterior and oblique roentgenograms of refracture through the site of an infected gunshot fracture of the femur which had been treated by sequestrectomy and intramedullary nailing. Nail had been removed after six months because of persistent drainage. (Courtesy of Armed Forces Institute of Pathology, Washington, D. C.)

Refractures

Management of refracture: Four patients with refractures were treated by plaster immobilization; six were treated by intramedullary nailing and bone-grafting; and the remaining eight patients were placed in traction-suspension. The added period of immobilization associated with this treatment for refracture varied between six and twenty-six weeks, the average being eleven weeks.

Increased morbidity due to refracture: Table I represents a study of the progress, the complications, the residual disability, and the eventual disposition of the patients with refractures as compared with the patients who had had no refracture. The groups have been simplified and reduced by eliminating such patients as those with paraplegia or hemiplegia, those who have had amputations, and those with other severe complicating injuries which altered and delayed their progress. From a consideration of only the relatively uncomplicated cases, the dramatic effect of refracture on the duration of recumbency, the period of hospitalization, and the recovery of function is clearly demonstrated. The economic, social, and functional implications of refracture are obvious and should serve to emphasize the need for efforts toward its prevention.

In addition to the increase in hospitalization time, the knee stiffness subsequent to the treatment of the refracture is a serious complication; it is probable that three of the thirteen patients in the refracture group who were eventually separated from military service for disability might have been returned to duty had it not been for this complication. Although the refractures in all of the eighteen patients eventually progressed to bony union, it will be noted that there were additional complications in this group secondary to the refracture. In five patients there were rather marked emotional disturbances with mental depression. These were temporary situations, but they might have been of serious importance. Renal lithiasis developed in two patients during their additional period of immobilization, and in another a severe gluteal atrophy developed with a subsequent persistent abduction limp.

ETIOLOGICAL FACTORS IN REFRACTURE

The eighteen patients with refractures were studied in an effort to determine the etiological factors. It was apparent that some of these factors were beyond control, whereas others were errors, either of the physician or of the patient, or a combination of the two.

Duration of Immobilization

In this regard it should be noted that our minimal period of traction-suspension for fractures of the femoral shaft had been arbitrarily set at twelve weeks, depending upon the clinical examination and the roentgenographic appearance. If these are considered to be satisfactory, there is an additional two-week period of suspension alone and then two weeks in bed or in a chair, followed by gradual ambulation with the use of an ischial weight-bearing caliper brace.

The patients treated by intramedullary nailing usually begin gradual ambulation with crutches at four or five weeks. The nails have not been removed before six months, and we now believe that a minimal period of one year should elapse before their removal.

It was our impression from the clinical histories and the examination of the roentgenograms that premature discontinuation of immobilization, with or without subsequent inadequate protection of the injured extremity, was the cause of refracture in nine patients. Anteroposterior roentgenograms of three patients showed what appeared to be adequate bone healing for discontinuation of the immobilization. Subsequent careful examination of the lateral views, however, revealed inadequate union which was partially concealed by the suspension apparatus. It is felt that if more adequate roentgenograms had been requested and examined, the immobilization would have been continued and the refrac-

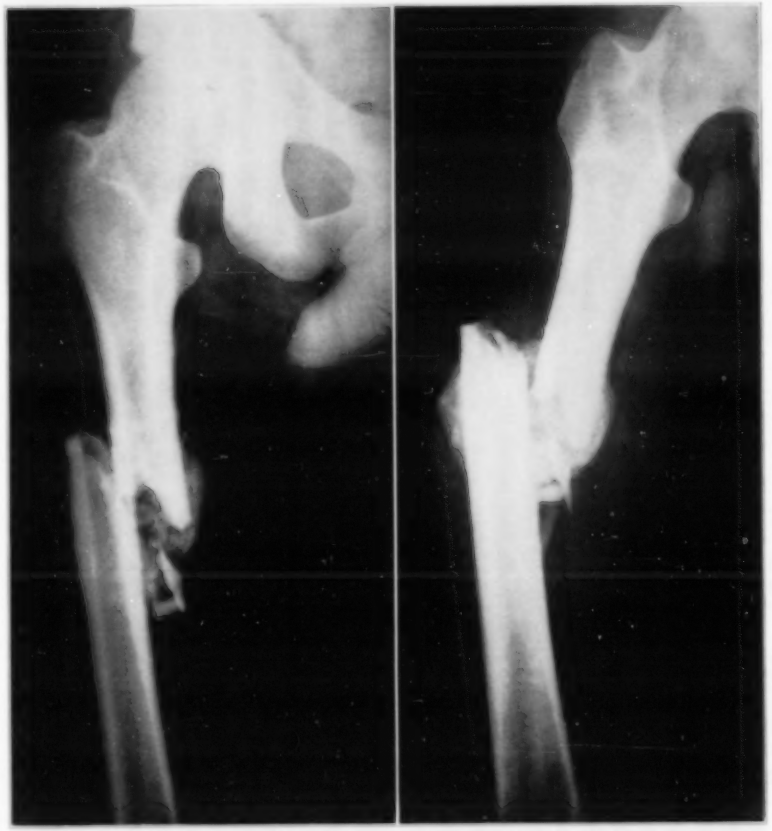

FIG. 3-A

FIG. 3-B

Fig. 3-A: Anteroposterior roentgenogram, showing inadequate reduction of fracture of the femoral shaft in a patient with paraplegia treated by traction-suspension for a period of twelve weeks. (Courtesy of Letterman General Hospital Photographic Laboratory.)

Fig. 3-B: Anteroposterior view, showing refracture and angulation which occurred during treatment for hip-flexion deformity. (Courtesy of Letterman General Hospital Photographic Laboratory.)

FIG. 4-A

FIG. 4-B

Anteroposterior and lateral roentgenograms of second refracture of the femoral shaft. First refracture had been treated by intramedullary nailing and bone grafting. The second refracture occurred at a lower level, eleven months subsequent to nailing, and was due to weakened quadriceps power and limitation of knee flexion.

ture might have been avoided. In three refractures, the inadequate immobilization was due principally to carelessness or to lack of cooperation on the part of the patients in keeping the extremities in the suspension apparatus. Three refractures followed premature removal of the intramedullary nails. In one fracture treated by nailing, there had been an electrolytic reaction between the nail and the encircling wire loops with resultant delayed union (Figs. 1-A and 1-B). When the nail was removed six months after insertion and ambulation was resumed with crutches but without weight-bearing on the extremity, refracture promptly occurred through the fracture area. It is possible that adequate union might have occurred if the nail had remained in the femur or even if a proper brace had been utilized after removal of the nail. There is some question whether this case should not be considered one of non-union of bone rather than refracture because of the roentgenographic appearance (Fig. 1-A).

Inadequate reduction should be considered as an important contributing factor. In one of nine patients in whom insufficient immobilization was considered to be the primary cause, there was the additional factor of inadequate reduction (Figs. 3-A and 3-B). When this situation is present, with its associated delay in bone healing and the production of altered weight-bearing stresses, the duration of immobilization should necessarily be longer and the protection of the limb in the convalescent patient must be increased.

Braces

Several authors have decried the use of a brace to support the extremity following the discontinuation of immobilization. These observers have expressed the opinion that the leverage effect of a brace on the fracture line, especially in high femoral fractures, may be such as to give very little support, and it may actually be the cause of refracture. Soto-Hall and Horwitz reviewed 163 patients with open fractures of the femoral shaft and reported five refractures in patients while walking with Thomas caliper supports. They suggested a longer period of suspension treatment with exercise and, if a brace is considered advisable, a modification of the ischial seat to bring the outer half of the ring above the level of the trochanter.

Three of the eighteen patients with refractures in this series sustained their additional trauma while wearing ischial weight-bearing caliper braces. In all of these, the original fractures had been located in the upper portion of the femur. Two other patients stated that their refractures were due to the manipulation involved in applying the braces to their lower extremities. This suggests the possibility that some patients may actually bear weight without their braces when not under immediate supervision, so that there is a certain factor of patient carelessness in this group, for which the braces themselves cannot be held responsible.

Other Factors

Hip deformities: Two of our patients had had definite flexion deformities of the hips at the time of refracture. In one patient, this constituted an added strain at the fracture site on weight-bearing. In another patient, attempted correction of the flexion deformity by the physical therapist was attended by refracture. Weakness of the hip musculature was also considered to be a factor in one patient; because of inadequate control of the extremity, refracture occurred when the extremity slipped over the side of the bed. One patient presented a varus deformity at the site of the fracture in the upper portion of the femur, and it was our impression that this should have been indication for a much longer period of suspension and, if possible, the subsequent avoidance of a brace. Certainly, braces should be used with caution in the presence of hip deformities.

Knee deformities: While there is no concrete evidence in this group that refracture was due to limited knee movement or to quadriceps weakness, there is the same theoretical possibility of such a factor as in hip deformities. Inability to control the knee on beginning

weight-bearing, especially when there is a limitation of knee flexion secondary to the initial immobilization, may be the cause of refracture. Attempted correction of such knee deformities by the physical therapist also may cause a refracture by placing an undue strain at the fracture site. In eleven of our eighteen patients, we know the range of knee movement just prior to refracture. Only one had flexion in excess of 90 degrees and three had flexion to 90 degrees. In the remainder of the patients, the considerable limitation of flexion might have played a part in the occurrence of refracture. It is known that quadriceps weakness was considerable in five of these patients. Uncontrolled flexion of the stiff knee was the mechanism of a femoral fracture in the patient represented in Figures 4-A and 4-B. The initial fracture had been treated by balanced traction-suspension, and the refracture had been treated successfully by intramedullary nailing and bone-grafting. When he was preparing to be discharged from the Hospital, with knee extension between 100 degrees and 180 degrees, he slipped and placed undue weight on his weakened knee in its fullest degree of flexion. This resulted in the supracondylar fracture.

Additional injuries: One of the refractures was due to unavoidable trauma in a patient with multiple amputations who could not properly control a slip of the fractured extremity. Three other patients were injured in accidents which were not attributable to carelessness. It is noteworthy that only four of eighteen refractures were due to such definite injury during convalescence.

Efforts in rehabilitation: It is our custom to start quadriceps exercises promptly in the management of fractures of the femoral shaft, and knee motion is begun as early as is consistent with adequate immobilization and the progress of fracture healing. After removal of the immobilizing apparatus, hip and knee exercises are increased, and there is the possibility of too strenuous efforts in rehabilitation being a factor in refracture. In only two cases of this group was there such a possibility, and in both there were other factors which played at least an equal part. It has not been our impression that the routine physical-therapy manoeuvres necessary for recovery of hip or knee movement play a primary role in the etiology of femoral refractures. However, the possibility must be kept in mind when such treatment is instituted, especially when progressive quadriceps-resistance exercises are employed.

Method of immobilization: There is no question in our minds concerning the greater likelihood of refracture in fractures of the femoral shaft treated by the conservative methods. Of the 135 fractures which we have treated from the time of initial injury, sixty-nine had been managed by traction-suspension and sixty-six by intramedullary nailing. Refractures occurred in nine (13.0 per cent.) of the traction-suspension cases, and in only three (4.5 per cent.) of those treated by nailing. The infrequency of refracture is obviously one of the many advantages of the nailing procedure when performed in properly selected cases and under optimum circumstances.

Previous infection: It is important to note that six refractures occurred in closed fractures and that ten of the twelve original open fractures had been due to missile wounds. While the comminution associated with gunshot wounds apparently predisposes to prompt bone healing in most patients, there are two elements in this type of injury which may lead to delay in union or eventual insecure union. One of these factors is loss of bone substance and the other is wound infection. Of our series of twelve original open fractures in which refracture later occurred, there was significant wound infection in two patients. These are factors in the incidence of refracture which are obviously beyond our control, but it is apparent that, under such circumstances, prolonged immobilization and protection of the extremity will be indicated.

Patient's error: In at least eight of our refracture cases, there was evidence of carelessness or lack of cooperation on the part of the patients. This was considered to be a contributing factor and not entirely responsible for the refracture in any individual case. It suggests, however, the need for greater supervision and instruction of these

patients, especially for the young active individuals with little sense of responsibility and often no great desire to be returned to military service. Regardless of care and instruction, however, a small percentage of refractures must be considered unavoidable because of these factors.

COMMENT

Analysis of the etiological factors in our patients with refractures reveals a startling incidence (66.6 per cent.) in which the complication was considered avoidable. While there was evidence of multiple factors in the etiology of the refracture in most cases, the principal causes were inadequate immobilization or inadequate subsequent protection in six, carelessness on the part of the patient in three, and premature removal of an intramedullary nail in three. Since the latter three cases must be considered cases of inadequate immobilization, they must be added to the six with inadequate traction-suspension and protection, making a total of nine patients for whose refractures the physician must be held responsible. Of the six patients whose refractures were thought to be unavoidable, four gave a history of a trauma sufficient to cause fracture in a normal femur. In one, the residual angulation at the subtrochanteric fracture site was considered to be the basic factor in the production of refracture, and in another no cause could be demonstrated.

As a result of this study, there are certain observations which may be helpful in the future prevention of refracture of the femoral shaft. Adequate reduction of the fracture is a primary consideration. While an average base line may be established for the duration of immobilization of fractures of the femoral shaft, strict adherence to any arbitrary period must not be practised, and generalization as to the duration of fixation must be carefully avoided. Stuck and Grebe reported twenty-one refractures in 124 consecutive fractures of the femoral shaft. They stressed the importance of adequate bone contact, of a much longer time for bone healing than generally accepted, and of a long period of protection to avoid subsequent injury. Each fracture must be considered on an individual basis, and the duration of protection must depend upon the clinical examination and the roentgenographic appearance of the fracture site. Satisfactory anteroposterior and lateral roentgenograms should be obtained. An acceptable roentgenogram in one plane only is insufficient evidence for the discontinuation of immobilization. Even after traction has been removed, the extremity should be protected for another two to four weeks in the suspension apparatus before the patient is permitted out of bed. The length of time of immobilization by any method of treatment should also be determined with regard to previous wound infection and loss of bone due to open injuries. Since refracture occurs frequently following open fractures, especially when either of the above two factors has been present, added protection of the extremity must be afforded the patient under such circumstances.

Intramedullary-nail fixation in appropriate fractures as the initial form of treatment will reduce the incidence of refracture. Premature removal of intramedullary nails, however, must be avoided, and a minimal period of one year should elapse before removal is considered. Nails should not be removed simply because of infection, although adequate drainage from such wounds must be maintained. Intramedullary fixation should be retained until definite union or definite non-union is established by the roentgenographic appearance.

Ischial weight-bearing caliper braces must be used with great caution. It is our feeling that such braces should be used in most cases; but, when there is a deformity of the hip due to angulation at the fracture site or muscle contracture, great care must be taken to avoid undue leverage strain at the fracture site. In patients with weakness of the hip musculature, similar precautions should be taken. Any patient with a fracture above the middle of the shaft must understand the potential danger to the fracture site in the

careless application or use of an ischial weight-bearing caliper brace. However, the advantages of the avoidance of complete weight-bearing on the extremity until the fracture has completely consolidated greatly outweigh the dangers of the brace in the great majority of cases. In this respect, it is our practice to instruct patients in the manner of supporting their braced extremities while getting in and out of bed or when seating themselves or arising. It is in these phases of the use of the brace, rather than in actual weight-bearing, that accidents usually occur.

Prior to the removal of the immobilization apparatus, all femoral-shaft fractures should be carefully evaluated as to the advisability of supplementary bone-grafting procedures. Some of the refractures in our series would undoubtedly have been avoided if bone-grafting had been performed to strengthen the site of fracture healing. In borderline cases, the decision to supply additional bone will probably prove conservative in the end.

Strenuous physical-therapy measures must be avoided in the convalescent treatment of femoral fractures, especially with regard to the correction of flexion deformities of the hip and of stiffness of the knee. Passive motions are rarely, if ever, indicated, and even progressive resistance exercises must be applied with the greatest caution. We make a practice of constantly reminding the physical-therapy technician to support and protect the site of the femoral fracture during the period of rehabilitation.

Finally, a thorough understanding by the patient himself of the problems associated with graduated ambulation and complete fracture healing may result in the prevention of many refractures. Very often the patient thinks that, because he is allowed out of bed, his fracture has healed and can tolerate ordinary activity. Greater care in the application and use of braces, avoidance of any activity which may incur trauma, and, above all, an awareness of the danger of unsupported weight-bearing until solid union has occurred will prevent many of these complications.

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A BACK-KNEE BRACE

BY HERBERT E. HIPPS, M.D., WACO, TEXAS

The brace to be described is of particular value in the treatment of the small child who has developed the habit of hyperextending the knee because of weakness of the quadriceps or of the glutaeus maximus, or of both, and in whom sometimes only weak knee flexors are present. The habit is pernicious because, when the child hyperextends the knee, quadriceps development does not occur with ordinary ambulation. The muscle is simply not called upon to maintain the knee straight as the child places his weight on the lower extremity. He pops the knee backward and locks it in hyperextension; he depends upon this position for knee stability rather than on the contraction of and strength of his quadriceps. Furthermore, with continual prolonged hyperextension, a deformity of the tibial condyles develops, which may later require surgical correction.

The older child usually can be trained not to hyperextend the knee, but the small child cannot. It was for this type of patient, in whom hyperextension has become a habit and in whom it is not a necessity for ambulation, that the brace was devised. Its use is based on the sound scientific principle of the development of a conditioned reflex or conditioned response. As the knee goes back into recurvatum while the child is wearing this brace, the skin of the back of the knee comes in contact with a sharp, short pin or tack point which is embedded in a felt pad. A slight pricking sensation is produced. The knee is then quickly drawn away from it. As the child does this repeatedly, a conditioned response is developed and the habit is thus broken.

The pin is so adjusted and fixed in the felt pad that it barely pricks the skin surface. In no instance has there been any damage to the skin of the popliteal space other than a slight red area measuring about two or three millimeters in diameter.

This brace has been used on fifteen patients since August 1953. In only two instances did the child re-acquire the habit of hyperextension of the knee after the brace had been removed. To each of these children the brace was reapplied. One child is still wearing the brace. The other wore it the second time for two additional months; it was then removed, and in

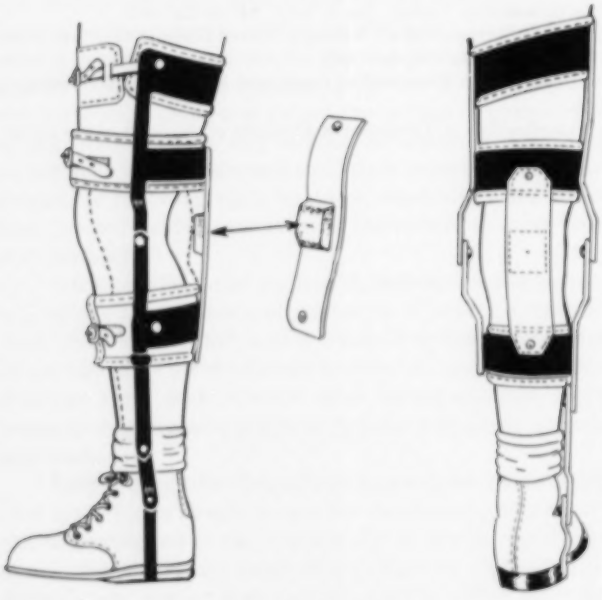

FIG. 1

Fig. 1: Insert shows the elastic webbing with a small piece of wool felt affixed to it. Note the pin sticking forward about one or two millimeters through the middle of the felt pad. The side view shows the elastic strap with the felt-and-pin device attached behind the knee to the calf band and to the lower thigh band. The dotted lines show how the back-knee position causes the pin to prick the skin of the back of the knee, thus making child draw the knee away from the pin. The back view shows the location of the elastic strap with the felt-and-pin device.

the four months since its removal he has not re-acquired the habit of hyperextension.

The following case histories illustrate the types of conditions in which it is of greatest value.

CASE 1. L. K., aged five. Eight months after poliomyelitis, all muscles had returned to normal except for a weak left quadriceps, grade *poor plus*, and a weak left glutaeus maximus, grade *fair*. The patient could walk without hyperextending the knee and did so in my office while I was looking at her, but at home she constantly walked with the knee hyperextended and routinely stood on the extremity in this way.

The brace was applied, she wore it for two months, and it was removed. Her habit of "back-kneeing" was completely broken, and her quadriceps had gained in strength so that it was then graded *fair*. Three months later she still had not regressed into her genu recurvatum habit. We have not seen her since then.

CASE 2. P. T., aged four. Thirteen months after poliomyelitis, the right lower extremity which had been weak had recovered almost completely. The only remaining weakness was in the quadriceps; it was graded *good plus*. However, the patient constantly and habitually hyperextended the knee. She could not be broken of the habit. The back-knee brace was applied, was worn for six weeks, and was then removed. At no time in the following nine months did she return to this habit.

CASE 3. J. D., aged six. Eighteen months after poliomyelitis, all muscles were normal except for the flexors of the left knee which were graded *fair*. The patient constantly walked with the left knee considerably hyperextended. The brace was worn for two months and during the eight months after it had been removed he did not re-acquire this back-knee habit.

BRACE CONSTRUCTION

The special feature of this brace is a piece of elastic webbing (Fig. 1) which runs from the middle of the back of the calf band to the middle of the back of the lower thigh band. On the front of the elastic webbing is fixed a small square piece of wool felt. In the middle of this piece of felt is a pin or tack so fixed that the sharp point is projecting forward about two millimeters beyond the felt pad. If the child's knee goes backward into hyperextension while the child is wearing this brace, the back of his knee touches the pin, and he immediately, reflexively, draws the knee away from it.

The metal part of the brace may be built in the same way as any other brace (Fig. 1), or the elastic strap, the felt pad, and pin may be attached to a thigh-length brace which the child may already be wearing. The brace may have any kind of ankle joint, but, of course, it must have a free knee joint.

The brace, as ordered by the author, is constructed of light flat steel. The brace is a thigh-length brace with a stirrup on the heel, a free ankle joint, a free knee joint, a calf band, and upper and lower thigh bands. It may be of single-bar or of double-bar construction; the latter, however, is preferred.

DISCUSSION

END-RESULT STUDY OF SIXTY-TWO STAPLING OPERATIONS

(*Continued from page 1070*)

scales or rules are used, it is desirable that the technician be well versed in the procedure. If he is not, and other less skilled personnel make subsequent films, one will become confused at the readings and soon find that there are no consistent roentgenographic criteria on which to base measurement of *growth progress*. In large hospitals, one x-ray technician should be in charge of this procedure.

Most of the staples will demonstrate spreading after four to eight months. This does not detract from the inhibiting action of the staples on growth.

Electrolytically positive metal caused us much concern during 1949 and 1950. Twelve patients, four to six months after operation, demonstrated rarefaction of bone about the staple ends. The staples appeared to be eroded. All of these children had their staples removed and replaced, with the exception of one. The removed staples demonstrated eroded ends with nests of carbon. Since this complication occurred, all new staples have been tested with a magnet by the charge nurse in surgery, and, if they jump to the magnet, they are, of course, discarded.

(*Continued on page 1086*)

FUNCTIONAL BRACE FOR THE PARALYZED HAND

A Preliminary Report *

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Assistance to patients with paralytic upper limbs has apparently received meager attention, judging from a search of the literature[1,2,3,4,5]. It is well known that amputees can secure some very fine and elaborate limb substitutes in this country. On the other hand, patients with hemiplegia and monoplegia must accept a useless limb as a permanent handicap. However, despite proprioceptive ability, patients with lower motor neuron lesions have to bear the useless member as a symbol of a dependent state.

Because of the hopelessness of these cases, consideration was given to the development of a functional brace to permit at least some measure of independence. For this purpose, the useless limb is made to serve as a pattern mold for a mechanically controlled brace and hook, so that simple functions of a hand can be carried out.

There are several advantages in such a functional brace:

1. Self-care activities, such as dressing, feeding, and carrying out the toilet, are permitted,—a distinct contribution to the rehabilitation process.

2. Vocational rehabilitation is made feasible.

3. Hobby or craft work is made possible, especially such forms as require bimanual abilities.

4. Psychologically, the patient's emotional recovery is assisted.

5. The proprioceptive and kinaesthetic senses which may be present are made use of in everyday living.

INDICATIONS

The suggested conditions for which such a functional brace can be prescribed are:

A. *Injuries* to the peripheral nerves, both median and ulnar; the brachial plexus; the nerve roots (unilateral); the muscle groups, such as flexors or extensors; and the brain (both traumatic and vascular injuries);

B. *Diseases*, such a poliomyelitis, arthritis, myelitis, radiculitis, and tumors;

C. *Congenital malformations.*

This list is by no means inclusive. Modifications of the basic features of this brace may be made to suit special needs and circumstances.

BIOMECHANICAL PRINCIPLES

Parts of the Brace

The harness is a suspension strap with associated controls to actuate the arm, the forearm, and the hook portions of the prosthesis (Fig. 1). It is designed to be as simple and inconspicuous as possible. The suspension strap has major loading points at the shoulder of the paralyzed side and the sound side. Cloth webbing is used as construction material with two leather attachments. A "figure-of-eight" is described with the free loop over the unaffected shoulder.

The controlling mechanism consists of a steel cable and mountings to actuate the hook.

The arm: A single two-inch leather cuff with buckle attachment is used to anchor

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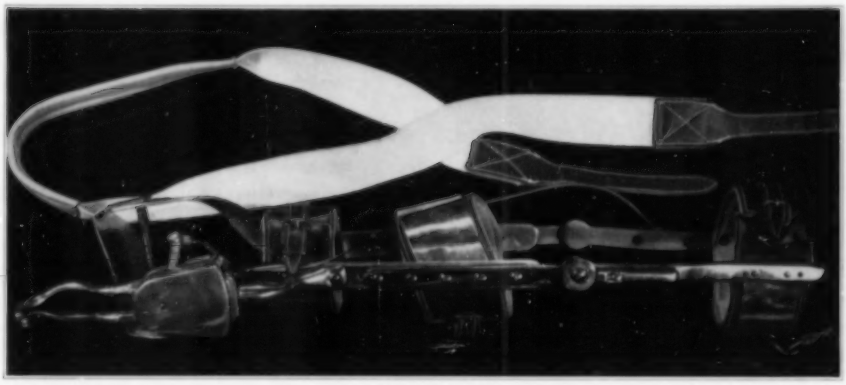

FIG. 1
Brace and harness.

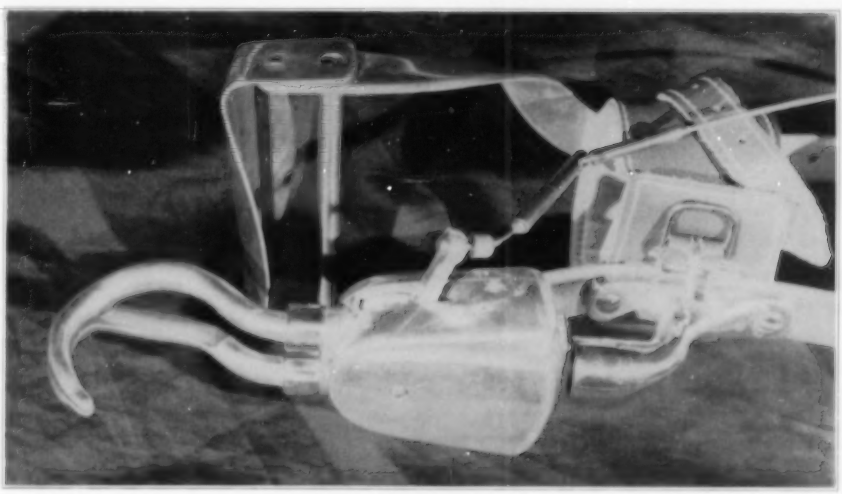

FIG. 2
Showing details of hook and guard.

and fix the upper end of the brace. The elbow joint consists of a through-pin joint. A manually controlled ratchet-type of lock is used on the medial upright; such an arrangement provides two locking positions between full flexion and complete extension.

The forearm: Two cuffs with buckle attachments are utilized in the forearm portion to provide a stable support. A coupling base for a screw or snap-in hook is attached on the medial aspect of the wrist.

The hand: When the hand is paralyzed, the fingers frequently are held in flexion. They have a tendency to obstruct and interfere with useful movements of the limb. Consequently, a curved guard is provided, not only to protect the hand and shorten the extremity but also to serve as the distal fixed end of the prosthesis (Fig. 2). The guard shown can accommodate most hand disabilities. Extending across from each side piece of the guard is a narrow round metal bar which comes to lie at the level of the metacarpal heads on the palmar aspect when the fingers are inserted. Rotatory motion of the brace thus becomes restricted, a decided advantage when fairly heavy objects require lifting.

The hook: The approved terminal device of the Army Prosthetic Research Labora-

tory is used (Fig. 2). The enclosed mechanism permits automatic locking or free movement of the hook arms.

Application of the Brace

A. The longer (anterior) perforated strap of the harness is fastened to the buckle attached to the upper leather cuff. The eyehole nearest the tip is used. The shorter (posterior) strap should be connected to the buckle which is continuous with the cable (Fig. 3). One of the middle eyeholes is selected for the tongue of this buckle.

B. The brace is placed on a table, and the three cuff straps are opened. With the elbow in the extended position, the hand and forearm are slipped through the center cuff and the wrist cuff, until the fingers or knuckles touch the metal guard. It is then found that the fingers will follow the curve of the guard until they face the hook as they reach the proper position. The transverse bar then lies in the palm of the hand. The distal cuff and then the center cuff are closed with the buckles. The ratchet lock is unlocked with the unaffected thumb or forefinger. This will permit the upper portion of the brace to be flexed, so that the proximal cuff will enclose the arm. The cuff may then be buckled closed easily.

C. The free loop of the harness is made to go over the normal shoulder by putting the sound hand through the loop as far as it will go and then, by raising the arm, the harness can be pulled over the head to the back of the neck. The harness readily comes to lie as shown in Figure 3, resting comfortably on both shoulders. The elbow is unlocked and the harness is tightened by shrugging the left shoulder forward. The normal limb is used to make any necessary adjustments to the harness straps, tightening or loosening them as required for comfort.

Operation of the Brace

A. The hook is operated by the shoulder control which is of the conventional type. After the appropriate adjustments have been made, the steel cable which is attached to the operating lever of the hook is made taut by fastening it in the proper eyehole in the control strap of the harness. A forward shrug of the unaffected shoulder or a reaching movement serves to tighten the cable and operate the hook.

B. A three-position slide switch is located on the outer aspect of the hook base. Changing the switch positions on the lateral face of the hook with the sound hand, a *voluntary-closing hook* or *automatic-locking hook* can be selected. In the central position, a free opening and closing of the hook is permitted. In the forward position, the hook locks on the object. In the rear position, the hook opens and cocks in preparation for locking at the next pull-to-close phase.

C. The control force is actuated by either arm flexion or a forward shrug of the opposite shoulder. This force is transmitted through the cable to the lever arm of the hook, producing the prehensile movements of the terminal device. Body motion produces the necessary work and excursion of the cable for operating the hook arms. The patient learns by practice and experience to transmit the amount of force necessary to perform various tasks. In holding a book of matches (by using the voluntary-closing hook) to be struck by a match in the sound hand, a moderately firm grip must be exerted by the hook. However, in a restaurant, when a tray of food is to be carried, several pounds of force is required.

Selection of the appropriate switch setting is dependent upon the job to be performed. For example, the voluntary-closing hook may be used to pull up a sock, whereas holding a telephone while dialing with the normal hand would necessitate the use of the automatic-locking mechanism. The automatic-locking arrangement serves admirably in preventing a constant strain on the control cable while an object is being held. With such a choice of mechanical changes, routine daily tasks, such as smoking, eating, and shaving, inherent to an individual's daily life, can be accomplished unaided with facility and security.

The model of the brace shown had been used experimentally on six patients with hemiplegia of the right side and on two patients with monoplegia of the right arm from poliomyelitis with such encouraging results that a brace with necessary individual modifications was prescribed for each.

Case reports of two representative types of paralysis are presented in order to indicate the benefits achieved with the functional brace.

J. S., male, aged fifty-one years, had been left with hemiplegia on the right side and aphasia following a cerebral thrombosis. Mental function had not been much impaired. A comprehensive program of treatment under the guidance of the Physical Medicine and Rehabilitation Service had rehabilitated him to the point where ambulation could be carried out. His flaccid upper limb, however, hindered his ability to learn self-care activities. For example, he could use a spoon or fork with his left hand to feed himself, but was unable to cut his meat. In dressing, he found it awkward to pull up his socks, underclothing, or trousers. He had great difficulty in tying his tie. Because of his aphasia, he conversed through the medium of writing, but the pad of paper kept slipping away from his pencil. When traveling by bus, he could take a handful of money out of his pocket with the unaffected hand, but had difficulty in selecting the appropriate coin for the fare box. After he began to wear the appliance, he was able to cut his own meat, and to dress himself fully; he had little difficulty in correspondence; he could select any coin from the palm of his left hand with the hook.

FIG. 3

Rear view of harness.

FIG. 4

Showing bimanual activity in using a knife and fork.

L. M., male, twenty-six years old, had a flail right forearm and hand following an attack of poliomyelitis two years previously. The deltoid, when manually tested, had shown only 40 per cent. of normal power, and the triceps 80 per cent. The biceps, brachioradialis, and the brachialis had retained only approximately 20 per cent. of normal power. The remainder of the muscles below the elbow were completely paralyzed.

Amputation had been considered, with a view to fitting a below-the-elbow prosthesis. After the functional brace had been given a trial, he demonstrated that it could readily meet his needs where bimanual activities were concerned. When wearing this brace, he had little difficulty in feeding and clothing himself. It became possible for him to do craft work, as well as to dial and hold a telephone. A door could now be opened easily, since, with the hook, he could insert a key into a Yale snap-lock and turn it while turning the doorknob concurrently with the normal hand. He was given an opportunity to drive a car and, after training, he was able to do so.

COMMENT

The advantages in the use of this brace are many and important. When amputation of a useless limb is considered, a trial period with this aid may be warranted. Often, one is surprised at the facility of its use after learning has been completed. Frequently, proprioceptive functions can exercise a useful role, even when motive power has been lost. In writing or holding the steering wheel of an automobile, these senses can be made to serve to some degree.

Needless to say, in older patients with paralysis or disease, an adaptive device may mean the difference between a useful or a useless individual in a household. If these people can be made independent of others for their basic needs, social adjustments may be considerably lessened.

Children afflicted with congenital malformation, paralysis, or absence of one limb may be fitted with a similar type of brace. The brace will encourage activity of the muscles and assist in psychological adjustment; considerable bimanual dexterity can be developed, and, also, it gives them the opportunity to engage in normal play with toys. It is surprising how remarkably proficient these youngsters become in the use of a utility hook.

The maximum utilization of the functional brace has not yet been realized for this type of patient. However, it seems clear now that with an aid as described he can become a useful member of society.

Acknowledgment is made to the Veterans Administration Prosthetic Aids and Sensory Service for their cooperation in the development of this brace.

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DISCUSSION

End-Result Study of Sixty-two Stapling Operations

(*Continued from page 1081*)

As in all operations, technique improves with experience. We feel that stapling, correctly performed, is not severely traumatizing and offers the surgeon better control of longitudinal bone growth than the Phemister epiphysiodesis. Stapling, in some degree, is reversible.

I wish to take this opportunity to thank Dr. Brockway and his associates for their critical analysis of this procedure and their results. We all learn from this type of presentation.

Dr. Cockrell (closing): I would like to thank Dr. Blount and Dr. Frantz for their comments and discussion. Possibly, the suggested change in title is appropriate.

We think that we have adhered to the technique as described by Dr. Blount as closely as we could, and we have followed our patients closely. Our x-rays are teleoroentgenograms; they are taken on a single cassette, equal to the lengths of the lower extremities and containing one or two large films, depending upon the lengths of the measured extremities. Multiple exposures are made vertically through a cone overlying the ankle, knee, and hip joints, as well as the mid-calf and thigh. These teleoroentgenograms are consistently measured by the roentgenologist of the Orthopaedic Hospital and are as accurate a method as there is. In 10 per cent. of our patients we placed staples subperiosteally, and actually in less than one half of these did there develop evidence of significant angular deformity or undesirable arrest in linear-growth length. We placed staples subperiosteally in our early patients only. Our series is comparatively small; however, many of our findings parallel those observed and described by Dr. Blount. As has been mentioned and emphasized, however, the percentage of desirable end results has been less in the group of patients with limb-length discrepancy.

MELVIN STARKEY HENDERSON

1883–1954

With the death of Melvin Starkey Henderson on June 17, 1954, American orthopaedic surgery lost one of its outstanding leaders of the generation just passed. Dr. Henderson was born in St. Paul, Minnesota, in 1883. He received his early schooling in St. Paul and later in Winnipeg, Manitoba. He received the degree of M.B. from the University of Toronto in 1906, and the degree of M.D. from the same institution in 1914. He was an intern in the City and County Hospital, St. Paul, from 1906 to 1907. He then went to Rochester to work as clinical assistant to the Mayo brothers. His interest in their work and the development of the Mayo Clinic never lagged from that time until his death.

During the years 1909 to 1911 Dr. Henderson worked as a surgical assistant to Dr. William J. Mayo and his colleagues. In 1910, looking to the future, Dr. Henderson felt that, in as much as he had always been interested in orthopaedic surgery, perhaps a section devoted to this specialty should be formed in the rapidly growing group. Such a move was proposed to the group, who after due consideration approved the idea.

Recognizing the developing specialty of orthopaedic surgery, the Mayo brothers sent Dr. Henderson to

Liverpool to work under Sir Robert Jones and to visit Sir Harold Stiles in Edinburgh, during the year 1911. He returned to Rochester and resumed charge of organizing and directing the Section of Orthopaedic Surgery at the Mayo Clinic. Thus, Dr. Henderson's experience was in a way unique in that he planned and organized and developed a section of orthopaedic surgery in a rapidly growing clinic devoted to group practice of medicine. Furthermore, he was vitally interested and took a very active part in the organization of graduate training at this institution under the auspices of the Graduate School, University of Minnesota, and was actively interested in the early development of The American Board of Orthopaedic Surgery.

Dr. Henderson contributed much to the growing specialty of orthopaedic surgery. His outstanding efforts were in the treatment of fractures, particularly bone-grafting procedures for ununited fractures and for fractures of the neck of the femur. He also developed an operation for the treatment of recurrent dislocation of the shoulder which became widely recognized. He wrote many papers on internal derangements of the knee joint and other orthopaedic subjects.

His work and interest in the development of modern orthopaedic surgery can be best illustrated by pointing out the various important posts he held in orthopaedic societies. He was Chairman of the Section on Orthopaedic Surgery of the American Medical Association in 1920. He was President of the Clinical Orthopaedic Society in 1920, of The American Orthopaedic Association in 1934, of The American Board of Orthopaedic Surgery in 1935, and of The American Academy of Orthopaedic Surgeons in 1936. He also held memberships in the American College of Surgeons, the International Society of Orthopaedic Surgery and Traumatology, the American Association for the Surgery of Trauma, the Western Surgical Association, the Minnesota State Medical Association, of which he was President in 1932, and the Southern Minnesota Medical Association, of which he was President in 1918. He was an honorary member of the Societas Orthopaedica Scandinavica.

These many activities show the breadth of the man and his great interest in seeing medicine and surgery advance on their broadest lines, and in seeing orthopaedic surgery develop from a very limited field devoted to the care of crippled and deformed children to a broad field of endeavor devoted not only to the care of cripples but to the prevention of crippling and disabling states by more advanced methods of treatment, both medical and surgical, and to the rehabilitation of persons crippled by disease and injuries.

His creed might be quoted from his own Presidential Address to The American Orthopaedic Association in 1934: "We as specialists must ever be on the alert to acquire knowledge pertaining to our specialty, and to assimilate, digest, and make use of new facts, thus acquiring that elusive something called wisdom."

R. K. G.

REPORT ON THE VISIT OF THE BRITISH AND COMMONWEALTH EXCHANGE FELLOWS IN ORTHOPAEDIC SURGERY

By Noel Wilson, Cardiff, Wales

The visit to America of the British and Commonwealth Exchange Fellows in Orthopaedic Surgery took place between April 27 and June 16, 1954. During this seven-week period, centers were visited on the East Coast of the United States and in Canada. The itinerary included New York, Wilmington, Philadelphia, Washington, Baltimore, Montreal, Toronto, Bretton Woods, and Boston.

It is my pleasant duty to record the experiences of those who took part in this tour, and to indicate our impressions of orthopaedics in the United States and Canada.

First, we would like to thank again the members of The American Orthopaedic Association and The Canadian Orthopaedic Association for their generosity in shouldering part of the financial burden of this venture, and to thank individual surgeons and their wives for the organization of programs and the wonderful hospitality which greeted us everywhere. We felt very honored that in every center we visited we were greeted and entertained by the leading orthopaedic surgeons of the day, many of whom had put themselves to no little inconvenience to do so. The experience we gained and the friendships we formed through all these personal contacts were, undoubtedly, the most valuable and enduring feature of our tour.

The first part of the Fellowship Tour was spent in New York, where we stayed for nearly three weeks. Although there is a great deal of ground to cover in this area, we felt that the time might be reduced in future years, in order to allow more time in other centers. We were met on our arrival by Dr. L. Ramsay Straub who immediately initiated us into the American way of life, with a mass of instructions, pamphlets, maps, and refreshments! We are deeply indebted to him and to Dr. T. Campbell Thompson for acting as our advisers throughout our stay in New York. We shall never forget our stay there. The immense size of the Presbyterian Hospital and Columbia Medical School, our flight over New York City in Dr. Bosworth's plane, the excellent instances of reconstructive surgery at West Haverstraw Rehabilitation Hospital and Westfield Children's Home, Manhattan Island by night from the Brooklyn water front, and a week-end at Larchmont are but a few of the happy memories of a memorable three weeks. At the close of the visit a unique dinner was arranged at the Century Club by Dr. Stinchfield.

From New York we moved on to Wilmington, Delaware, where we stayed at the Du Pont Institute, in the most luxurious residents' quarters we had ever seen. From there we visited Philadelphia; and we are deeply grateful to Dr. Shands, not only for his hospitality, but also for his faultless organization which moved us smoothly to and from the outlying hospitals. In Philadelphia we saw a series of late results of Colonna's operation, as excellent as anyone could possibly wish for. These results convinced most of us that, properly applied and properly executed, this is a first-class operation. Dr. John Royal Moore arranged a very beautiful demonstration of his osteotomy-osteoclasis and, in his own inimitable way, gave us much food for thought.

Washington was our next center, and there we were given a change from intensive orthopaedics. Most of the week-end was spent sightseeing, but there was, as well, a most interesting morning at the George Washington University Hospital, where incidentally we saw some excellent results of primary prosthesis for fractured neck of the femur. Another morning was spent at the Naval Medical Center, Bethesda, where the highlight was a demonstration of the technique of "freeze-drying" bone. The kindness of Dr. Peterson and his colleagues and the excellent program they arranged made this a most pleasant week-end.

It was as well that we were given a brief respite in Washington, because in Baltimore we were greeted with a very full program. This started on the evening of our arrival with a meeting of the Baltimore Orthopaedic Group, where one of our members gave a short paper. We saw and talked about many orthopaedic cases in the five days we were in Baltimore, and met a number of very interesting people. We were intrigued by the activity and vitality of Dr. Bennett and learned many things from his store of experience. At the Johns Hopkins Hospital we were impressed by the high standard of the academic work which was being carried out, not only in orthopaedics, but in all other branches of medicine. At the Children's Hospital School and at the James Lawrence Kernan Hospital and Industrial School for Crippled Children, we were shown many interesting cases, and we feel that we gained much from the provocative discussion which ensued.

Baltimore marked the end of the first part of the tour in the States and from there we flew to Montreal. It seemed that even the weather had been arranged especially to make us feel at home when we arrived in Canada—we landed in a thunderstorm. There we were met by Dr. Petrie and Dr. Favreau. The following day the latter drove us to Quebec, where we were graciously entertained by Dr. Roy and his colleagues. We were grateful to these surgeons for the opportunity to see so much of their beautiful city. In Montreal itself, McGill University, the University of Montreal, the clinical demonstrations at the Hospital of the Sacred Heart and the high standard of work at the Shriners' Hospital are perhaps our most vivid impressions.

Toronto was the third city to be visited in Canada, and we spent a short, but very intensive period there before going on to Bretton Woods, New Hampshire, for The American Orthopaedic Association meet-

ing. One could not help but be impressed by the very active inquiring minds of the orthopaedic surgeons in Toronto, and by the attention to research that this gave rise to which was apparent everywhere. A cross section of the nature and extent of the research work being carried out was given to us in a series of papers presented in the Banting Institute; but, quite apart from this, the recognition of the importance of investigation was evident in all the work presented to us.

The record of the visit to Toronto would be incomplete without mention of the great kindness shown to us by Dr. and Mrs. Harris. Their hospitality, their thoughtfulness, and their friendliness we can never forget, and particularly memorable was the visit to the flood-lighted Niagara Falls.

The American Orthopaedic Association at Bretton Woods marked a reunion with many friends we had made in the previous six weeks. Four pleasant days were spent in very beautiful surroundings with an excellent scientific program and social entertainment. There was, however, some sadness in our hearts, because we knew well that this might be the last time we would meet many of the surgeons and their families who had been so kind to us throughout our stay in the States; that thought made each one of us determined to return one day to renew these friendships so dear and so invaluable to us.

Our final visit was to Boston and was all too short. We feel that, in the future, very much more time should be allowed for a visit to this center. Boston has so much to offer in orthopaedics that we were very conscious of the fact that we were able to touch only the fringe of it. Even that was inspiring. Consider for example the large and efficient Fracture Service at the City Hospital — here is a hospital dealing with an immense number of casualties and so holding endless lessons on how to evolve an appropriately efficient department. We spent a most instructive afternoon at the Massachusetts General Hospital with Dr. Barr and his colleagues in an impromptu discussion of a wide variety of orthopaedic problems, and it occurred to us all that more use might be made of this type of discussion for future traveling fellows. We are also indebted to our hosts for introducing us to that excellent local habit—the Boston clam bake.

So our visit drew to a close. Our last official engagement was the farewell dinner in the Harvard Club, and there, in the club of one of America's oldest universities, we said good-bye.

It is not easy to give one's general impressions of American orthopaedics. I think it is fair to say that we all had certain preconceived and sometimes erroneous notions of what we should find when we got to America, and we were surprised to find that our differences were few and our methods very similar. The pattern of the orthopaedic services is very much the same as our own, with the exception that the American services are less hampered by financial worries—a point which sometimes made us very envious. The conference method of discussing cases, which was customary everywhere we went, could be developed to an advantage in more centers in Great Britain. We were particularly struck by the efficient way in which the resident staff presented their cases at these conferences, and the manner in which the younger men were encouraged to give their opinions.

We felt that there were certain definite differences in approach to some problems which are worth mentioning. For instance, there seemed to be a great preference for open reduction of fractures and the use of internal fixation, in cases in which we might have considered conservative treatment permissible and even advisable. It was felt that, to a certain extent, this practice was intended to reduce the patient's stay in hospital to a minimum with a view to reducing expenses. Perhaps, too, the nursing staff was not sufficiently expert in the care of patients "in splints" (for example, fractures of the femur) to obtain good results by conservative methods.

Another difference between our respective clinical approaches encountered in many centers lies in the treatment of tuberculosis. We could not quite appreciate the rationale of early fusion in tuberculous joints, with its incidence of pseudarthrosis and sinus formation, when the possibilities of good antibiotic treatment are remembered.

We hope that the Exchange Fellowship has come to stay and that others from both sides of the Atlantic may benefit from a similar opportunity. We felt that the number chosen this time was ideal, allowing as it did close contact with our opposite numbers in North America and enabling us all to meet and talk easily and informally with great men in orthopaedics. These close scientific and social contacts might be lessened or even lost if the group were larger.

The value of these Fellowships in graduate training is far beyond anything that can be obtained in the routine orthopaedic course. It is probable that the greatest benefit was derived by those of us who are already responsible for organizing our own services, or who are just at the end of their training, and it is from this level that future Fellows should be chosen. As we look back upon what we have gained from our experiences in Canada and the United States, it is not any one or other spectacular new idea or treatment which comes immediately to mind, but rather a vast array of facts that have widened our general knowledge of orthopaedic surgery and have led us nearer to essential wisdom and common sense, which are so vital to its practice.

EXCHANGE FELLOWSHIPS

In 1955 the program of Exchange Fellowships between Great Britain and North America, sponsored jointly by The American Orthopaedic Association, The British Orthopaedic Association, and The Canadian Orthopaedic Association, will send five Fellows from North America to Great Britain where they will be guests of The British Orthopaedic Association. Four Fellows will be selected from the United States and one from Canada.

The American Orthopaedic Association contributes $500.00 toward the traveling expenses of each Fellow from the United States; The Canadian Orthopaedic Association contributes $500.00 to the Fellow chosen from Canada, and The British Orthopaedic Association contributes the sterling equivalent of $500.00 to each of the five candidates toward their expenses while in Great Britain.

The tentative program calls for the Fellows to arrive in Great Britain about the first of May, join The British Orthopaedic Association in its visit to the *Société française d'Orthopédie et de Traumatologie* in Paris on May 5, 6, and 7, and then return to spend five or six weeks at orthopaedic centers in Great Britain.

The Committee on Exchange Fellowships both of The American Orthopaedic Association and of The Canadian Orthopaedic Association invite any young orthopaedic surgeon in the United States or Canada who may be interested in going to Great Britain in 1955 as an Exchange Fellow to make application at once to the Secretary of The American Orthopaedic Association (in the case of candidates from the United States) or to the Secretary of The Canadian Orthopaedic Association (in the case of candidates from Canada) in order that their qualifications may be considered by the selection Committee.

Applicants should be not more than forty years of age; they should have completed their training in orthopaedic surgery; they should have passed the examinations of The American Board of Orthopaedic Surgery or the Royal College of Physicians and Surgeons of Canada, and they should be established in the active practice of some branch of orthopaedic surgery (university teaching, clinic practice, private practice, or research).

Applicants should submit details of their education, training in orthopaedic surgery, appointments past and present, military service, and contributions to surgical literature. Forms for this purpose may be obtained from the Secretaries of The American Orthopaedic Association and The Canadian Orthopaedic Association, or from members of these Associations and from Fellows of The American Academy of Orthopaedic Surgeons. The application should be supported by two sponsors, members of The American Orthopaedic Association, Fellows of The American Academy of Orthopaedic Surgeons, or members of The Canadian Orthopaedic Association. Endorsement by the chief of the orthopaedic service where the candidate has had most of his orthopaedic training would be valuable to the selection Committee.

Will members of The American Orthopaedic Association and The Canadian Orthopaedic Association and Fellows of The American Academy of Orthopaedic Surgeons please call this opportunity to the attention of their young colleagues and support the application of those who they believe would benefit.

The closing date for applications will be December 31, 1954.

CORRECTION

An error appeared in the Proceedings in the summary of the paper presented by Dr. Gerald G. Gill, Dr. John G. Manning, and Dr. Hugh L. White, entitled *Surgical Treatment of Spondylolisthesis without Spinal Fusion* (*Excision of the Loose Lamina with Decompression of the Nerve Roots*) as published in the June issue of *The Journal*.

On page 684, paragraph 3, line 4, the phrase "and, where indicated, a superior facetectomy", and on the same page, paragraph 6, line 2, the phrase "with superior facetectomy, occasionally" should have been omitted.

It is suggested that a line be drawn through these phrases by the reader in his June issue.

Proceedings

THE VIRGINIA ORTHOPAEDIC SOCIETY

The Annual Clinical Meeting of the Virginia Orthopaedic Society was held in Norfolk, Virginia, on Friday, March 26, and Saturday, March 27, 1954, under the presidency of Dr. Bernard D. Packer. Arrangements for the meeting were made by the Norfolk members of the Society under the chairmanship of Dr. John Vann.

Brief summaries of the papers presented follow:

Low-Back Pain. Dr. Arthur A. Kirk [1] gave an excellent review of the current literature on low-back pain. He went into the question of sciatica thoroughly and discussed the relationship of disc conditions to sciatica. In addition, he emphasized the many causes of sciatica and low-back pain, as well as the pathological damage in the discs. Particular stress was laid upon the intervertebral foramen and its relation to the nerve root, together with the pathological conditions found in this area, which create a root-compression syndrome.

Chondromalacia of the Patella. Dr. John S. Thiemeyer, Jr. [2], reported twenty-one cases of chondromalacia of the patella, 20 per cent. of which had had arthrotomies, and all of which were under observation. He reported that in only 48 per cent. of these cases was there any history of trauma, usually of long duration. Four of the cases had old fractures of the patella, and in only 3 per cent. was the trauma that of a lateral strain. The most frequent locations of trauma, in his cases, were in this order: the medial facets, the medial portion of the patella, and the lateral facets. The most frequent subjective symptoms were pain, swelling, instability, difficulty in climbing stairs (one-third of the patients), and locking (one-third of the patients). He stated that 55 per cent. exhibited pain on pressure and only 8 per cent. had crepitation. Most of the pain was aggravated by quadriceps resistance. Roentgenographic changes were apparent only in the late cases. Twelve of these patients had had previous surgery, which in each case had consisted in total patellectomy. Initial treatment, Dr. Thiemeyer stated, consisted in rest and exercises. He did not feel that hydrocortone, injected locally, was of any benefit. For the cases which required surgery, he felt that partial or complete excision of the patella was the treatment of choice. In the patients who had had previous surgery, he had performed a total patellectomy. Since these operations were performed while he was in the Navy, no end results were available.

Interesting Tumors of the Humerus. Dr. Wieman H. Kretz [3] and Dr. F. Ashton Carmines [4] presented one case of a bone cyst, one case of eosinophilic granuloma, one case of chondroblastoma, and one case of osteolytic-osteogenic sarcoma, all of which were initially difficult diagnostic problems.

Hip Prostheses. Dr. George G. Hollins [5] presented a report on the use of hip prostheses in seven patients. One patient had bilateral fusion of the hip; after surgery he was able to get about, with difficulty, with the aid of crutches. The second patient had aseptic necrosis; after surgery he was able to get about without crutches or cane. His chief complaint was pain in his knees. In the third patient, there was congenital dislocation of the hip with osteomyelitis secondary to surgery. The Trendelenburg sign was negative, but the patient walked with a cane. The fourth patient had osteo-arthritis; after surgery, he walked with support and complained of pain. Bilateral aseptic necrosis, in the fifth patient, was somewhat improved after surgery; but the patient still walked with support. The sixth patient, with arthritis of the hip, was walking with a crutch, after surgery, but he had occasional pain in the back and hip. The last patient had bilateral degenerative arthritis. He had been improved by the insertion of a prosthesis in each hip. The Trendelenburg sign was negative. He had some pain on extension. The result in this patient appeared to be the best in the group. The limitations and difficulties connected with prostheses were thoroughly discussed.

A case of Fanconi's syndrome in which the diagnosis was established by roentgenograms was presented by Dr. John Foster [6]. An excellent discussion of the pathological changes in Fanconi's syndrome was presented by Dr. John Bos [7]. A brief review of the changes in the blood chemistry in this and related conditions was given.

[1] 108 Fort Lane, Portsmouth, Virginia.
[2] 343 Wainwright Building, Norfolk, Virginia.
[3] 2814 West Avenue, Newport News, Virginia.
[4] 2804 West Avenue, Newport News, Virginia.
[5] 229 West Bute Street, Norfolk 10, Virginia.
[6] De Paul Hospital, Norfolk, Virginia.
[7] De Paul Hospital, Norfolk, Virginia.

Fractures of the Tibia. Lt. Comdr. F. E. Thornton [5] presented 102 cases of fracture of the tibia treated during the year 1953 at the Portsmouth Naval Hospital. Of these, seventy-six were simple and twenty-six were compound fractures. Ten fractures were presented as examples of the following types: transverse, short oblique, long oblique, butterfly (comminuted), and segmental or double. The type of treatment, whether the fracture was simple or compound, did not vary provided that there had not been a time lapse of more than fifteen hours before the fracture was seen or that there had not been extensive soft-tissue damage with loss of circulation.

Conclusions governing the treatment of each type of fracture are as follows: For transverse fractures closed reduction with cast fixation should be employed if possible; for complicated transverse and oblique fractures open reduction with the insertion of an intramedullary nail of the Lottes or Rush type and cast fixation are indicated. Two or more transverse screws may be used on oblique fractures; the screws are countersunk from the lateral side when the condition of the skin permits. For the butterfly type of fracture, treatment depends upon the position of the fragments.

The treatment of choice when practical and in order of preference is as follows: closed reduction and cast, open reduction and transverse screw fixation, double-pin fixation above and below the fracture site, incorporation of the limb in a cast when the skin condition permits, and (as the last choice) bone-grafting with plating or the insertion of an intramedullary nail. Plates can be used successfully in the upper two-thirds of the tibia, but it is felt that they are definitely contra-indicated for use in the lower third. Fractures of the segmental or double type should be treated by intramedullary nailing, if at all possible. Most complications—for example, infection, non-union, and delayed union—were found at the junction of the upper two-thirds of the tibia with the lower one-third.

Reconstructive Surgery of the Hand in Cerebral Palsy. Dr. J. Leonard Goldner [5], the guest speaker, presented an interesting and instructive motion picture dealing with reconstructive surgery of the hand in cerebral palsy.

Following this Dr. Goldner presented a paper entitled "Lesions of the Spine Resembling Ruptured Discs", which was considered by all present to be very timely.

Interesting cases were presented by the Staff of the Naval Hospital and with each there was a general discussion.

The following officers were elected for the year:

President: Bernard D. Packer, M.D., Richmond, Virginia;
Vice-President: Allen Ferry, M.D., Arlington, Virginia;
Secretary-Treasurer: William M. Deyerle, M.D., Richmond, Virginia.

THE TEXAS ORTHOPAEDIC ASSOCIATION

The Texas Orthopaedic Association met on May 3, 1954, at San Antonio, Texas. Dr. Edward T. Smith, Houston, presided; the program was arranged by Dr. John Hinchey, Vice-President.

The following papers were presented:

Fractures of the Astragalus. Dr. Philip L. Day [1] emphasized the importance of prolonged immobilization in plantar flexion until there was evidence of healing. The foot was then gradually brought up into dorsiflexion.

The Management of Soft-Tissue Scars and Defects of the Anterior Portion of the Leg. Dr. C. W. Tennison [2] and Dr. E. P. Waller [3] showed that many cases of soft-tissue scars and defects of the anterior portion of the leg occur in active young people, usually as a result of trauma. Split-thickness skin grafts are not satisfactory. A double pedicle sliding graft, moved in stages, was recommended as the procedure of choice.

Replacement of the Proximal Humerus and Distal Radius by Fibular Graft. Dr. R. A. Murray [4] presented two interesting cases in which the fibula was used as a replacement for the proximal portion of the humerus and the distal portion of the radius.

Discrepancy in Leg Length and Growth of the Extremity. Dr. William T. Green [5] discussed the problem of limb-length discrepancy and recounted the history of the approach to this subject. He emphasized that there is still a place in certain conditions for limb-lengthening, limb-shortening, and stapling; but, if an accurate estimate of growth can be calculated, the operation described by Phemister is the most satisfactory one to follow.

[5] United States Naval Hospital, Portsmouth, Virginia.
[5] Duke University Hospital, Durham, North Carolina.
[1] 1108 Nix Professional Building, San Antonio 5, Texas.
[2] 414 Navarro Street, San Antonio, Texas.
[3] 414 Navarro Street, San Antonio, Texas.
[4] 1110 North Eighth Street, Temple, Texas.
[5] 300 Longwood Avenue, Boston 15, Massachusetts.

Sacrococcygeal Chondroma. Dr. David R. Oliver[6] presented a case of sacrococcygeal chondroma and told of the problems encountered in its management.

In the afternoon, a program was presented by the Army Staff at Brooke General Hospital. Mass casualties and experiences in the treatment of fractures of the long bones in the Korean conflict were discussed. They emphasized that intramedullary nails may be used successfully in mass civilian casualties.

Cases were presented of Hodgkin's disease, primarily manifest in bone, and echinococcus disease of bone. A Vitallium elbow prosthesis was demonstrated.

Gunshot wounds of the hip were reviewed, and it was demonstrated that this is an extremely shocking condition. General measures to combat shock, early wound débridement, with secondary closure and immobilization of the part, had markedly reduced the mortality.

A review of 102 cases of compound fractures of the tarsal bones resulting from land mines and trip flares was presented. These injuries consisted of all types of fractures; the results ranged from amputations to resumption of full duty within a short period of time.

Utilization of hydrocortone in arthrotomy of the knee was found to be of no particular postoperative value in fifty-four cases.

Fractures of the shaft of the tibia at Lockland Air Force Base were reviewed. Various methods of treatment were employed, depending upon the site and extent of the fracture.

The business meeting of the society was held following the clinical session and the following officers were elected:

President: Brandon Carrell, M.D., Dallas, Texas;
Vice-President: Duncan McKeever, M.D., Houston, Texas;
Secretary-Treasurer: Margaret Watkins, M.D., Dallas, Texas.

Dr. Frederick R. Thompson, New York, N. Y., and Dr. William T. Green, Boston, Massachusetts, were elected Honorary Members of the Texas Orthopaedic Association.

THE AMERICAN ORTHOPAEDIC ASSOCIATION

Annual Meeting, 1954

The Annual Meeting of The American Orthopaedic Association was held at the Mount Washington Hotel, Bretton Woods, New Hampshire, on June 7, 8, 9, and 10, 1954. Dr. Alfred R. Shands, Jr., presided, aided by the Vice-President, Dr. Leo S. Lucas. The last previous meeting of The Association to be held in New England took place in 1930 at Boston, Lakeville, and Chatham, Massachusetts, under the presidency of Dr. Z. B. Adams.

Forebodings concerning the weather were only partly realized; for, in spite of the earliness of the season, it was comfortably warm much of the time. The sun shone; and afternoon and early-morning tennis, golf, swimming, walks, motor trips through the mountains, and taking in the handsome view of the "white hills" contributed richly to the enjoyment of the meeting. The early fears that cold weather and poor travel facilities at that time of year would mar the occasion gave way to the realization that the meeting was, in fact, one of the most enjoyable and satisfactory.

The scientific sessions, held each morning from nine to one, were of unusual interest and value clinically and from the standpoint of basic science, thanks to President Shands and his indefatigable and resourceful Program Committee, with Dr. Lenox Baker as Chairman. Notable, too, was the Symposium on Crippled Childrens' Services, held on the afternoon of the first day of the meeting.

Two developments took place during the meeting which bid fair to be especially far-reaching through their influence on research. One was the substantial progress which was made by the Orthopaedic Research Society toward perfecting its organization. The Society was established last January, under the presidency of Dr. Paul Colonna, for the purpose of facilitating critical discussion among scientific investigators to help in the solution of problems arising in the course of original research. An announcement of the scope, plans, and first regular meeting of the Society will appear in the December issue of *The Journal*. The other development was the formal introduction of the Orthopaedic Research Foundation proposed by Dr. Shands during his presidency to receive, manage, and direct the raising of funds for research. Announcement of the proposal to organize such a foundation was made by Dr. Shands in his Presidential Address, published under the title "Responsibility and Research in Orthopaedic Surgery" in the July issue of *The Journal*.

Among the many distinguished guests were Prof. Walter Mercer of Edinburgh, President of the Royal College of Surgeons of Edinburgh, and Mrs. Mercer, Mr. S. Alan S. Malkin, of Nottingham, England, former President of The British Orthopaedic Association (1948–1949), Prof. T. Garofalides of Athens, Greece, and many prominent surgeons of New Hampshire and Vermont.

[6] 414 Navarro Street, San Antonio, Texas.

On Monday evening, June 7, the President's Reception was held at which were presented the members elected July 2, 1953, at the close of the 1953 meeting.

Later in the evening, illustrated talks were presented on New Hampshire and the Mt. Washington Weather Station by Mr. David Heald of Concord and Mr. Joseph B. Dodge of Gorham, New Hampshire.

The Annual Golf Tournament of The Association was held on Tuesday afternoon, June 8, on the attractive Bretton Woods course. The skies cleared as though for the occasion and, in spite of the fairways being slow due to recent heavy rains, the play was spirited and the competition was keen. In the ladies' division, low score went to our Scottish guest, Mrs. Mercer; among the men Robert Ramsey's gross of 80 took first, second prize went to Walter Hoyt with a gross of 81. Five tied for low net: Leo Lucas, C. T. Flynn, Stuart Russell, Edward Compere, and Edward Evans. Of these, first prize was drawn by Stuart Russell of Hanover, New Hampshire; the second prize went to Edward Compere.

The annual banquet of The Association was held on Wednesday, June 9, attended by 241 members and guests. Following the introduction of guests of honor, President Shands called on Dr. George Bennett who responded with a droll speech in story-telling vein. Then Prof. Walter Mercer of Edinburgh spoke and none who were present will forget the warmth and sincerity of the message of good will and comradeship he brought and his appeal to keep the bond intact between peoples of the English-speaking nations that their ideals may be maintained inviolate in a troubled world.

At the Second Executive Session held on June 10, Dr. J. Warren White of Honolulu, the President for the coming year, was inducted into office. The following officers and members of committees were elected:

Officers

President-Elect: Paul C. Colonna, M.D., Philadelphia, Pennsylvania;
Vice-President: G. Edmund Haggart, M.D., Boston, Massachusetts;
Secretary: George O. Eaton, M.D., Baltimore, Maryland;
Treasurer: H. Page Mauck, M.D., Richmond, Virginia.

Committee Members

Membership Committee: Frank E. Stinchfield, M.D., New York, N. Y.;
Program Committee: J. Vernon Luck, M.D., Los Angeles, California;
Research Committee: William H. Bickel, M.D., Rochester, Minnesota.

Representatives on The American Board of Orthopaedic Surgery

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George J. Carpenter, M.D., Nashville, Tennessee;
John A. Heberling, M.D., Pittsburgh, Pennsylvania.

Elected to membership were the following:

Capt. Chalmers R. Carr, Bethesda, Maryland;
Dr. Lee T. Ford, Jr., St. Louis, Missouri;
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Dr. Loren J. Larsen, San Francisco, California;
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Dr. George S. Phalen, Cleveland, Ohio;
Dr. Joseph C. Risser, Pasadena, California;
Dr. Robert A. Robinson, Baltimore, Maryland;
Dr. Peter E. Sabatelle, San Juan, Puerto Rico;
Dr. William J. Schnute, Chicago, Illinois;
Dr. Mary S. Sherman, New Orleans, Louisiana;
Dr. Donald B. Slocum, Eugene, Oregon;
Dr. Edward T. Smith, Houston, Texas;
Dr. Henry F. Ullrich, Baltimore, Maryland;
Dr. Paul C. Williams, Dallas, Texas;
Dr. Peter B. Wright, Augusta, Georgia.

Dr. Fuller Albright, Boston, Massachusetts, was elected an Honorary Member.

Prof. Walter Mercer, Edinburgh, Scotland, Dr. Ryosuke Katayama, Tokyo, Japan, and Dr. Robert Soeur, Brussels, Belgium, were made Corresponding Members.

The next Annual Meeting of The American Orthopaedic Association will be held at The Greenbrier, White Sulphur Springs, West Virginia, June 19 to 22, 1955.

Summaries of the presentations made during the scientific sessions follow:

MONDAY, JUNE 7, 1954

Idiopathic Scoliosis: Experimental and Metabolic Studies. DR. I. V. PONSETI[1] and DR. GENEVIEVE STEARNS[2] summarized their experimental studies on rats and their metabolic studies in children with idiopathic scoliosis. In rats fed diets containing sweet-pea (*Lathyrus odoratus*) seeds widespread lesions developed which varied with the age of the rats and the duration of the diet. The lesions occurred in areas in which the ground substance was known to contain chondroitin sulphate as the only mucopolysaccharide or the main mucopolysaccharide; these were thought to result from a defect in the ground substance which was, possibly, caused by the defective formation or excessive destruction of the chondroitin sulphate. The following lesions were described in the rats fed the experimental diet:

1. In the spine, kyphoscoliosis developed in young animals; this was caused by the slipping of the vertebral epiphyses without involvement of the discs but with resultant wedging of the vertebral body. Two lesions were prerequisite for the development of this deformity: (a) changes in the epiphyseal plate, characterized by widening, loss of cohesion, and fibrillation of the cartilage matrix, followed by slipping and rent formation in the transitional zone of calcification of the plate, and (b) loosening of the ligamentous attachments to bone. In some animals, lesions reminiscent of adolescent kyphosis with wedging of the vertebral bodies were noted.

2. In the long bones, the epiphyseal plates became wide, the cartilage matrix disintegrated in the plane between the zones of proliferation and calcification, and, in some animals, epiphyseal slipping ensued. The periosteum had been pulled away, especially at the sites of muscle and tendon attachment, with resulting new-bone formation and cartilage formation. In some cases, abundant new cartilage and bone developed beneath the periosteum; this presented a picture reminiscent of infantile cortical hyperostosis. Areas of hemorrhage and degeneration beneath the tibial tuberosity, with changes suggestive of Osgood-Schlatter disease, developed in some young rats.

3. In the joints, degenerative arthritis occurred after several months on the diet. This was characterized by (a) degeneration of the articular cartilage (fibrillation and formation of nests of cartilage cells) and (b) by loosening of the capsular and ligamentous insertions.

4. In the spines of older rats, degenerative changes in the intervertebral discs, with the formation of spurs and the development of herniations of the disc both posteriorly and into the vertebral bodies occurred.

5. In one rat, necrosis, flattening, and fragmentation of the femoral head produced a lesion closely resembling lesions seen in Legg-Perthes disease.

6. In older rats the cortical bone became thickened and the metaphyses became dense. Histologically these dense bones presented a mosaic trabecular structure resembling that seen in Paget's disease.

Biochemical studies now in progress have identified β-glutamylaminoproprionoitrile in *Lathyrus odoratus* seeds. This substance, or similar substances, in the sweet pea may be that which interferes with the metabolism of chondroitin sulphate.

Metabolic studies in children with idiopathic scoliosis have shown (1) a normal calcium metabolism, (2) an increased urinary nitrogen revealed when the urinary nitrogen of these children was compared with that in normal children of the same age and with the same nitrogen intake, (3) an abnormally abrupt rise in urinary amino acids following increased nitrogen intake, (4) urinary excretion of many amino acids, especially of taurine and methionine, as shown by chromatographic studies, (5) a high urinary excretion of sulphur derivatives, (6) a normal serum vitamin A, (7) a low serum vitamin E (tocopherols), and, frequently, (8) a low serum carotene.

The authors conclude that it is the matrix rather than the mineral components of bone and cartilage which is involved in the experimental animals, that the abnormal nitrogen and sulphur excretion in children with idiopathic scoliosis may indicate a disturbance of the metabolism of chondroitin sulphuric acid, and, finally, that the pathogenesis of the experimental lesions in rats fed diets containing the seeds of the sweet pea may be similar to that of idiopathic scoliosis and many other common diseases of the skeleton.

DR. I. WILLIAM NACHLAS[3] noted that this work suggests that scoliosis is a manifestation of a systemic disease. As further support of this, he cited the work of Duraiswami, who produced scoliosis in chickens by the injection of a chemical into the egg of a developing chick embryo, and the studies of Dr. Fremont Chandler, who found that patients with scoliosis had other osseous deformities, particularly of the palate and teeth. Dr. Nachlas's own studies on rickets revealed that slipping of the entire epiphysis comparable to that seen in Dr. Ponseti's rats occurred. He remarked on the value of the experiments done by Dr. Ponseti and Dr. Stearns in shedding light on the pathogenesis of scoliosis, but he raised several questions which must be

[1] State University of Iowa, Iowa City, Iowa.
[2] State University of Iowa, Iowa City, Iowa.
[3] 1109 North Calvert Street, Baltimore 2, Maryland.

answered,—namely, why should there be a striking sex relationship in this deformity with four to five girls affected to one boy and why do we not see more generalized evidence of osseous involvement in the human patient with scoliosis.

Dr. Joseph A. Freiberg [4] noted that in scoliosis only the spine is affected, as far as is known, while in Dr. Ponseti's rats generalized osseous lesions occurred.

Avascular Necrosis Involving Articular Surfaces. Dr. W. Edward Gallie [5] recounted the natural process of repair and replacement in damage to joint surfaces and restated the principles of healing which are involved. He said he did so, not without hesitation, in the face of the present enthusiasm for quick restoration through artificial replacement of large portions of joints. When a portion of a joint surface, such as the capitellum, becomes cut off from the blood supply, as by avulsion, the bony element dies and the cartilaginous covering lives, the chondrocytes receiving the nourishment they require from the joint fluid. The bony component must be absorbed and replaced by new bone through ingrowth from adjacent osteogenic sources. To help nature complete the restoration most effectively, apposition must be firm and immobilization must be complete. Revascularization and replacement cannot be expected to advance beyond certain limits, as was shown in some accurately reduced and fixed fractures of the femoral neck. It is also true that joint transplants must be autogenous; homogenous and heterogenous material will die. Conceding a place of usefulness for artificial joint-surface replacements, Dr. Gallie warned that we, as surgeons, must look to the study of the great principles of anatomy and physiology to maintain our position rather than to the "comparatively simple mechanics of the machine shop".

In discussing Dr. Gallie's presentation, Dr. Robert I. Harris [6] affirmed the experiences which Dr. Gallie had reported. He emphasized that cartilage transplants must be autogenous and not homogenous. He indicated another condition in which the principle is of value,—namely, in certain cases of osteochondritis dissecans. He showed lantern slides made from roentgenograms of a patient with that condition in whom the lateral femoral condyle was involved. Because of persisting symptoms, he had operated upon the knee three years after the injury which had produced the fragmentation. The bed was freshened and the two fragments were replaced, being held fixed by pins. The result was entirely satisfactory anatomically and functionally, the patient becoming symptom-free.

In closing, Dr. Gallie made a strong plea that young men who are entering upon a career in orthopaedic surgery spend a good deal of time in research and in the investigation of fundamentals.

Arthrodesis of the Hip by Wide Abduction in Massive Destruction of the Joint. Dr. LeRoy C. Abbott [7] and Dr. Donald B. Lucas [8] presented a method of securing arthrodesis of the hip when there is extreme loss of the joint through destruction of the femoral head, the femoral neck, or a portion of the acetabulum. In 1931, Abbott and Fischer presented the method as one to meet the difficulty of obtaining fusion of the hip in the presence of massive destruction of the joint by tuberculous or pyogenic infection. As performed at that time the method was carried out in three stages: The first stage consisted in the correction of deformity by traction. If the greater trochanter was bound by adhesions to the ilium, it was first freed by excision of the scar before traction was applied. Traction was so managed that shortening was corrected, and the position of wide abduction was secured. The second stage consisted in débridement of the joint and acetabular decortication, excision of whatever remained of femoral head and neck, removal of the muscle attachments and cortex of the greater trochanter, and the placing of the denuded upper end of the remaining bone in wide abduction in the acetabular excavation. Tension of the abductors exerted compression on the apposed cancellous bony surfaces. Fusion occurred in a high proportion of the patients (64 per cent. of the first eleven). The third stage, a subtrochanteric osteotomy, which was performed to restore the limb to the functional position, was carried out when it was established that fusion was solid. The authors stated that the method is again presented because of the broader field of application which it now has in treatment of non-union and aseptic necrosis of the femoral head and neck, in sepsis following cup arthroplasty, in congenital dislocation, and in Legg-Perthes disease, when other methods have failed. Furthermore, there has been modification of the procedure in that traction has been omitted, since it was almost never necessary. It is also apparent that the method is not widely known; this is attested by Kirkaldy-Willis and Mbuthia who, in a recent article, described the method as little known and one which may not have been recorded. Moreover the authors now perform the subtrochanteric osteotomy earlier, as soon as consolidation of the fusion area has become evident, and they correct the position at the time of the osteotomy, thus greatly shortening the period of hospitalization.

In his discussion, Dr. Rudolph Reich [9] emphasized the principles underlying this method of arthrodesis,—firm apposition of cancellous bony surfaces, compression through the tension of the adductors, and

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[5] Medical Arts Building, Toronto, Ontario, Canada.
[6] 170 St. George Street, Toronto, Ontario, Canada.
[7] University of California Hospital, 3rd and Parnassus, San Francisco, California.
[8] University of California Medical Center, 3rd and Parnassus, San Francisco, California.
[9] 10515 Carnegie Avenue, Cleveland 6, Ohio.

immobilization which is probably very nearly absolute. He found it difficult to accept the authors' statement that a probable average shortening of one and one-quarter inches following fusion by this method would result; he felt that the shortening would be greater, especially when the osteotomy was low and the degree of abduction high. He thought that the method would produce a higher percentage of successful primary fusions than any other and that the report was timely if for no other reason than that it might be valuable when failures had occurred with the use of hip prostheses.

An Analysis of End Results of Surgical Treatment of Major Ligamentous Injuries of the Knee. Dr. Don H. O'Donoghue [10] presented a critical analysis of eighty patients upon whom he had operated for major injuries of the knee during the fifteen-year period 1938 to 1954. Of the eighty patients, forty-two were examined by the author personally at follow-up, twenty-nine were followed by means of an ingenious questionnaire designed to produce accurate and complete information, and nine had sufficiently detailed records to provide the necessary specific information sought. Follow-up varied from over six months and less than one year in sixteen to over ten years in five; the average was three and one-third years. In the series, there was only one patient under fifteen years of age; there were forty-six from sixteen to twenty years, and twenty from twenty-one to twenty-five years. Placing great importance on early operation, Dr. O'Donoghue divided his patients into three categories: *early*, comprising those operated upon within two weeks of the time of injury, *late*, those operated upon between two weeks and three months when scar retraction should be complete, and *reconstruction*, those operated upon over three months after injury. The results clearly support such a grouping.

In answer to the question whether the knee bothered, 70 per cent. of those in the early group replied in the negative, while only 40 per cent. in the late group and 50 per cent. in the reconstruction group answered no. To the query is your knee as good as the other, 53 per cent. of the early group believed it was as good, while 30 per cent. in the late group and only 25 per cent. in the reconstruction group felt so. Of the early group, 86 per cent. are completely happy with the outcome, while in the late group 75 per cent. and in the reconstruction group 88 per cent. said they were happy with the outcome. In the early group, 90 per cent. of the patients participated in athletics, while only 63 per cent. in the late group and 40 per cent. in the reconstruction group did so. Nine patients (60 per cent.) in the reconstruction group had had a complete tear through the substance of a cruciate ligament. These nine did not return to athletics.

In a special system of rating in which ten points constituted a perfect score in answer to each of ten questions, the forty-four patients in the early group received an average of eighty-seven points; the twenty patients in the late group averaged seventy-seven points; and the sixteen patients in the reconstruction group averaged seventy points.

Injuries involving the medial side of the joint constituted 84 per cent. of all cases. Injuries in 30 per cent. involved the medial collateral ligament, the anterior cruciate ligament, and the medial meniscus; injuries in 20 per cent. involved the medial collateral ligament and the medial meniscus; and injuries in 20 per cent. involved the anterior cruciate ligament and medial meniscus. Injuries to the lateral side structures comprised 7.5 per cent., and injuries to the cruciate ligament alone involved 8.5 per cent. of the cases.

The operative technique was described in detail in the paper and in a previous publication in *The Journal* (**32-A**: 721–738, Oct. 1950).

In discussion, Dr. George E. Bennett [11] postulated four requisites to success in knee-joint surgery of this type: that the patient be seen very early, that the surgeon be a good diagnostician, that the surgeon have good judgment, and that he possess skill of the first order. Regarding reconstructive surgery for old knee injuries, he could not agree that a complete rupture of the anterior cruciate ligament meant complete disability, as far as athletics is concerned. He cited a case which he had treated by reconstruction. The knee had been disabled by a rupture of the anterior cruciate ligament, and he had plicated the tibial collateral ligament and had removed the remnants of the torn anterior cruciate ligament. Later the patient had made the All-American Soccer Team and two years after injury became its captain. After that experience, Dr. Bennett had performed the operation many times with consistent success. He felt that chronic relaxed knees with fractured or displaced menisci could not be fully restored to normal by simple meniscectomy. Reconstruction of the tibial collateral ligament had been necessary in all of these cases.

Dr. J. S. Speed [12] also felt that Dr. O'Donoghue had made an important contribution to the surgery of knee-joint injury by his operations, which ideally meant early repair. He had not found reconstructive surgery easy. In late cases, he had simply done a meniscectomy, as long as the knee on examination was stable. He did this in spite of a tear of the anterior cruciate ligament, provided, of course, the patient did not wish to resume violent contact athletics. Other patients required meniscectomy, in addition to which he tried to restore a moderate amount of the stability which had been lost. In these patients, too, he included only those patients who did not intend to resume violent contact athletics. In addition to meniscectomy, he tightened the tibial collateral ligament by transferring its femoral attachment proximally. In patients with grossly un-

[10] 1111 North Lee Street, Oklahoma City 3, Oklahoma.
[11] 4 East Madison Street, Baltimore 2, Maryland.
[12] 869 Madison Avenue, Memphis 3, Tennessee.

stable knees, the results of surgery had, in his experience, been only fair; these patients were left with some instability and some traumatic arthritis, and most of the time they had pain. He had had one All-American football player in this group. He stated that he repairs all ruptured ligaments surgically, if necessary by substitution. Some of the brilliant success that Dr. O'Donoghue had achieved, he felt, was due to his very careful postoperative care.

In closing, Dr. O'Donoghue made a plea for early recognition and early surgery; he emphasized that reconstructions were very much more difficult than the primary repairs.

The Symposium on Crippled Children's Services was opened by the moderator, President Shands, who welcomed Dr. Martha Eliot, Chief of the Children's Bureau, Department of Health, Education, and Welfare, Dr. H. R. Kobes, Director of Crippled Children's Services, State of Illinois, and three foreign representatives, Prof. Walter Mercer of Edinburgh, Scotland, Mr. S. A. S. Malkin of Nottingham, England, and Dr. T. Garofalides of Athens, Greece. Dr. Shands stated that the purpose of the conference was to bring about a fuller realization of the concept of the crippled child as a whole and of our responsibility as orthopaedic surgeons to the solution of the problem. In meeting this responsibility, the orthopaedic surgeon, sociologist, psychologist, social worker, and educator must combine their efforts.

The first speaker, Dr. George E. Bennett [13], told of his early years with Dr. William Baer in Baltimore during the period 1910 to 1912. They realized then that the rehabilitation of the crippled child involved three important phases,—physical rehabilitation, education, and vocational training. To these ends the Children's Hospital School was established in Baltimore. Later, Dr. Bennett was one of the members of the Medical Advisory Committee, appointed in 1935, shortly after the Children's Bureau had begun to function. The other members were Robert B. Osgood, Albert H. Freiberg, and Oscar L. Miller. During this early period, Dr. Bennett worked in close cooperation with Dr. Martha Eliot.

Dr. Martha Eliot [13], a woman of distinguished appearance, read a carefully prepared manuscript, outlining the function and the history of the Children's Bureau. She stated that the Bureau was not intended to dominate but rather to guide, to keep informed, and to improve old methods. It was intended to help formulate standards of orthopaedic care and to help develop new ideas. It left to the individual states the responsibility of determining the types of crippling conditions they should include. Although other conditions, such as deafness, blindness, and cardiac disease, have been added to the categories included by the Bureau, orthopaedic conditions still comprise more than 50 per cent. of the total. During the years 1940 to 1954, Federal funds appropriated for the Bureau have increased two and one half times and state funds have increased fourfold. In the year 1954, estimated expenditures will be $40,000,000, of which about $10,000,000 will be supplied by the Federal Government, $30,000,000 by the states. In 1952, nearly 238,000 children were cared for. Today the social and psychological implications of crippling are better understood. Dr. Eliot pointed out that the program of child care must be carried out under the leadership of the physician and stressed the need for teamwork between physician, physical therapist, nurse, teacher, and social worker. Of particular importance are preventive measures; although our means at present are scanty, further research may have a marked effect. [The speaker evidently had in mind the present vaccination against poliomyelitis.] Recently the role of the parents has been emphasized: Parents' organizations have been formed to help them gain skills, to aid them in overcoming guilt feelings, and to facilitate discussion of their problems with one another and with the physician that they may be more fully informed and come to understand. An attempt is now being made to reduce the period of hospitalization to a minimum, and, while the child is in the hospital, to have the mother with the child as much as possible. Infants should be fed by the mother. Convalescence should, whenever possible, be in the home rather than in an institution. This applies to children of school age, as well as to infants. In line with this principle, crippled children should, wherever possible, be included in regular school classes rather than in separate groups; this, of course, requires a highly elastic school program which is not easy to formulate.

Recent advances in the care of the crippled child have been greatly helped by the development of improved hearing devices, which has been facilitated by electronic discoveries, and new prostheses based on extensive research.

Dr. Eliot concluded by emphasizing the role crippled children will play when they grow up. They represent a significant percentage of the population. They are exposed to discrimination and rejection. They need the bulwark of family trust and affection; they must have health, physical and mental, and a sense of social well-being.

Dr. H. R. Kobes [14] presented the viewpoint of the state administrator and spoke about the state program. The first state to develop a well rounded plan was Minnesota; this was in operation before 1900. Other states followed slowly until thirty-seven had some form of state program at the time of the establishment of the Children's Bureau in 1935. Thereafter all the states soon had organized programs, usually under the

[13] Chief of the Children's Bureau, Department of Health, Education, and Welfare, Washington, D. C.
[14] Director, Crippled Children's Services, State of Illinois, Springfield, Illinois.

aegis of the department of health, and frequently headed by a pediatrician. The service is open to all children without regard to race or religion. In Illinois, his own state, there is a staff of three full-time administrators, one of whom is a full-time staff member of the University of Illinois College of Medicine, and twenty nurses, supplemented by a consulting staff of specialists, certified by their respective boards. There has been no difficulty in securing an ample number of qualified physicians. The state is divided into forty areas, and clinic sessions are held in each area with the idea of bringing the physician to the child. About 260 clinic sessions are held annually. Each child is given a thorough examination, after which he is referred to the appropriate doctor, public health nurse, and social worker. A special education program has been organized. By these means, there is a close interplay between the local authorities and the state. Private organizations, such as The National Foundation for Infantile Paralysis, the Shriners, the Elks, and local groups, are encouraged to help. The state pays for such appliances as braces, artificial limbs, hearing aids, and dental prostheses, in accordance with the financial status of the family. During the past few years, the increasing number of cases covered by insurance has diminished the financial burden of the state. The doctors are paid for travel expenses and are given a small professional fee. The total staff numbers about 125, and nearly 30,000 children are under their surveillance. Of these children, about 10,000 receive some form of service; this ranges from a single visit by a public health nurse in the home to hospital and medical services costing $4,000 or $5,000.

In closing, Dr. Kobes pointed out that the crippled children's program will always be needed; there will always be families in need of help because the care of crippled children is expensive and it is prolonged — often for many years. "Sooner or later", according to the report of the Commission on Chronic Illness, "chronic disease and poverty become synonymous". Tremendous amounts of money, energy, intelligence, and character are needed to deal with many orthopaedic conditions which are in their very nature, at least at present, long and drawn out. Only when the largest possible number of physically handicapped children can be brought to a point where they can take their places as useful and productive members of society may we feel our programs have accomplished their aim.

Dr. William T. Green [15], speaking for the orthopaedic surgeon, injected a critical note into the symposium. He felt that there had been much too little contact between the Children's Bureau and the orthopaedic surgeons who were doing the actual work. Recently, since the establishment, in 1950, of the Children's Bureau Technical Advisory Committee, there has been a closer cooperation with orthopaedic surgeons. He felt strongly that in the allocation of Federal funds and in the allocation of program patients in need of hospital care, preference should be given to those institutions in which, in addition to their care for the crippled child, an active teaching program and organized research were being conducted. In this way the funds would help to create a group of doctors qualified to carry on the rehabilitation of the crippled child.

Dr. A. Bruce Gill [16], acknowledging the all-important work of the Children's Bureau, emphasized the importance of local lay societies. Although these frequently started in a most modest way, they have continued to exist despite panics and financial upheavals, because they are so dear to the hearts of the people. Their great advantage is that they are voluntary, not compulsory. He feels strongly that nothing should be done by the state or Federal government to lessen the interest of the local group. His own tendency is, therefore, to discourage too much governmental control. In this way political complications could be avoided. Of course, when problems arose which could not be faced by the local groups, the state should step in. These concern chiefly the coordination of various groups and the more efficient development of research.

In listening to the next speaker, Prof. Walter Mercer [17], it was of particular interest to hear him stress the same facts as Dr. Kobes,—namely, that the organization of a crippled children's service must bring the orthopaedic surgeon to the child, or, as he phrased it, "the orthopaedic surgeon must go out to the periphery". He described the organization of the eight counties composing the southeastern district of Scotland. At the center is the Princess Margaret Rose Hospital of Edinburgh, a unit of the Royal Infirmary, with workshops, a therapeutic pool, as well as modern operating rooms and open air wards. He described it as "a happy hospital". In the surrounding counties are six general hospitals for accident cases and short-term patients. There are numerous peripheral clinics, major and minor, so arranged that the children attending them could continue at school. Thanks to this local development, orthopaedic cases are discovered early and treatment is simplified.

Mr. S. Alan S. Malkin [18] said a good word for the British National Health Service. Thanks to it, every child has been able to receive treatment and the necessary apparatus and appliances. Special schools have been started for the education of crippled children; and, after completing the school curriculum, each pupil

[15] 300 Longwood Avenue, Boston 15, Massachusetts.
[16] 365 Penn Road, Wynnewood, Pennsylvania.
[17] 12 Rothesay Terrace, Edinburgh 3, Scotland.
[18] 54 The Ropewalk, Nottingham, England.

is eligible to receive three years of special training. By the Act of 1944, the Minister of Labour was empowered to provide rehabilitation centers. Praiseworthy though these government regulations were, he found that there was a tendency to overlap efforts. Therefore, in Nottinghamshire, a local voluntary association was formed to act as a coordinating body. Personally, he had to admit that as an orthopaedic surgeon he is not too happy about the results of treating cerebral palsy, and he is frankly puzzled about the most efficient method of treating acute poliomyelitis. He referred to the research committee, of which Mr. Seddon was chairman, which has been organized to study this problem.

The last speaker, DR. T. GAROFALIDES [19], told about the Hellenic Crippled Children's Society, organized in 1937, which he said was heavily supported by the Near East Foundation and the Greek Rotary Club. The number of children cared for has increased rapidly, from 988 in 1949 to 2,334 in 1953. Those needing operative treatment are admitted to his hospital in Athens. A modest brace shop has been organized. There are six women therapists and two instructors. Some children are placed in private homes in Athens during the time of treatment.

In summarizing the important aspects of the symposium, the reviewer found the following ideas to be of significance: Federal and state organizations are of great importance in the coordination of effort, in the determination of standards of procedure, and in financing. They cannot, however, replace the local organization, which is personally acquainted with the crippled child. The more efficient the central organization, the more it will try to bring the doctor and the nurse to the crippled child. As Prof. Mercer said, "the orthopaedic surgeon must go out to the periphery". The parents must be made important members of the team concerned with the rehabilitation of the crippled child. Therefore, the child should be separated from his family and from others his own age for a minimum period of time during the physical and educational rehabilitation.

TUESDAY, JUNE 8, 1954

Failure of Excess Minerals in the Diet to Accelerate the Healing of Experimental Fractures. DR. J. ALBERT KEY [20] and DR. RICHARD T. ODELL [21] called attention to the publicity given, during recent years, to the area of Deaf Smith County in Texas as the result of the low rate of tooth decay. This has been said to be due to the mineral content of the food and water in this locale. The same explanation has also been applied to the rapid healing of fractures in that area and the absence of intracapsular fractures of the neck of the femur, as reported by Dr. L. B. Barnett.

In order to determine experimentally the possible influence of excess minerals on fracture healing, Dr. Key and Dr. Odell fed rats the minerals which were present in this geographical region, according to the analyses of Dr. Barnett, in the same proportions present in food and water in Deaf Smith County. Two groups of rats were used: a control group which was fed a normal sustaining diet, and an experimental group which was fed a normal sustaining diet to which had been added the minerals in the proportions found in diets in Deaf Smith County. The experimental rats were given a daily mineral intake of about three times the amount, when compared proportionally, of the mineral intake of the inhabitants of Deaf Smith County. One hundred and thirty rats were used; these were divided into two groups. The first group consisted of thirty animals, fourteen of which were fed a standard diet and sixteen of which were fed a standard diet to which the minerals had been added. The right femur in each was fractured and no form of immobilization was applied. Of the second group (100 rats), fifty were fed the standard diet and fifty were fed the diet containing excess minerals. In these rats, the humeri were fractured, and the bones were maintained in position by a stainless-steel pin. The animals were studied at different time intervals,—the first group being sacrificed at five to sixty days after fracture and the second at two to twenty-one days after fracture. The fractured humeri and femora and the normal humeri and femora in the same animal were studied. After comparing the clinical and microscopic findings in these bones, Dr. Key and Dr. Odell were not able to see any major difference between the rate of fracture healing in mineral-fed rats and in the control animals. Excess mineral intake did not seem to have a significant influence on the rate of fracture healing; however, union occurred slightly earlier in more of the mineral-fed rats than in the control rats. It was observed that the mineral-fed rats gained more weight than the control animals.

The authors concluded that there is no significant increase in the rate of healing in fractures in rats receiving an excess of the minerals found in Deaf Smith County in Texas. The immobilized fractures healed faster and better than those not immobilized.

This study was made on animals on adequate diets; just what the result would be in animals on inadequate diets will have to be a problem for future study.

[19] Solonos 130, Athens, Greece.
[20] 4952 Maryland Avenue, St. Louis 8, Missouri.
[21] 600 South Kingshighway, St. Louis 10, Missouri.

The Use of Radio-Active Phosphorus (P^{32}) *to Determine the Viability of the Head of the Femur.* Dr. H. B. Boyd [22], Dr. D. B. Zilversmit [23], and Dr. R. A. Calandruccio [24] reported on experimental studies of a method of predicting avascular necrosis of the head of the femur following fractures of the femoral neck. The method consisted in the intravenous injection of radio-active phosphorus (P^{32}) and the use of a Geiger-Müller tube (originally devised by Robinson to localize brain tumors) which is inserted into a hole in the femur made by a guide wire. Counting rates are obtained one and one-half hours later at the time of surgery from the head of the femur and from the trochanteric area; from these a ratio is calculated.

Experimental studies on dogs revealed that this ratio was affected by interruption of the blood supply.

Clinical data were obtained from fifty-three patients, with thirty-two acute fractures of the femoral neck, ten fractures of the trochanteric region, eight old fractures with varying degrees of avascular necrosis, a single case of non-union of a fracture of the femoral neck, with questionable avascular necrosis, and a case of traumatic dislocation of the hip which required open reduction. The authors felt that final evaluation of the method must await the clinical end results in tested cases in a large series.

In discussing this report, Dr. John J. Fahey [25] expressed the view that if P^{32} were injected immediately after intracapsular fracture and if counts were made one and one-half hours later, the ratios would be the same as those obtained by the authors. He, therefore, felt that the counts as presented in the group of patients with fresh fractures are an indication of vascularity rather than of viability of the femoral head.

Comparison of the Beneficial Effects of ACTH and Cortisone and the Deleterious Effects of Immobilization in Paget's Disease. Dr. Philip H. Henneman [26], Dr. Frederick C. Bartter [27], Miss Eleanor F. Dempsey [28], Miss Evelyn L. Carroll [29], and Dr. Fuller Albright [30] compared the effects of immobilization with the effects of the administration of ACTH and cortisone on bone metabolism in Paget's disease. In this disease, the urinary calcium and alkaline phosphatase are markedly elevated. The authors' theory of the pathogenesis is that localized bone destruction caused by some unknown process results in reduced bone mass which in turn increases the stress and strain on the remaining bone. This serves as a potent stimulus to osteoblastic activity; the result is the characteristic histological picture of concurrent bone production and destruction and the typical metabolic disturbance of high calcium excretion due to bone destruction and a high alkaline phosphatase due to excessive osteoblastic activity. In Paget's disease, for example, immobilization after a fracture produces a rapid fall in alkaline phosphatase associated with a rapid rise in urinary calcium, as well as, in some cases, a rise in the serum calcium and phosphorus levels. When mobilization is resumed, the alkaline phosphatase rises while the urinary calcium, serum calcium, and phosphorus fall. The authors interpret these changes as indicating that in compensated Paget's disease, the calcium being mobilized by bone destruction is more or less balanced by that going into new-bone formation, while with immobilization the stimulation of the osteoblasts (skeletal stress and strain) is eliminated and bone destruction predominates. This leads to the characteristic metabolic changes. Balance studies on a patient with Paget's disease following first a fracture and later a corrective osteotomy illustrated these changes.

In contrast, when ACTH was given to two patients with Paget's disease, a sudden fall in urinary calcium resulted which persisted for approximately eighteen days; urinary calcium then gradually returned to the control levels. Associated with this was a fall in the serum calcium and phosphorus in one and in the alkaline phosphatase in both patients. The latter occurred as the urinary calcium began to rise. In one patient, the alkaline phosphatase fell from 90 to 45 Bodansky units and in the other from 50 to 5 Bodansky units at the end of therapy.

A third patient was treated with cortisone by mouth for thirty days; twelve days after cessation of the drug, she was put to bed with the right leg placed in Russell traction to simulate the effects of immobilization after a fracture. At the start of their study of her case, the urinary calcium fell from 250 milligrams in twenty-four hours to a low of sixty milligrams in twenty-four hours; it then returned toward the control level during the administration of the drug. The serum calcium also fell, but the alkaline phosphatase did not change. When immobilization was initiated, these changes were reversed. The urinary calcium rose to 770 milligrams in twenty-four hours; the serum calcium and phosphorus also rose, while there was a slight fall in the alkaline phosphatase. Thus the effects of ACTH and cortisone are the exact opposite of those of immobilization. Furthermore, the effects of ACTH and cortisone in Paget's disease are the reverse of those in normal persons.

Finally, the third patient, who complained of deafness and tendinitis, was relieved of the deafness twenty-four hours after cortisone therapy was begun, and the distressing aches and pains in her bones disappeared. The blood flow to her skeleton was thought to be diminished, for her dilated tortuous temporal

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arteries decreased in size and her ankle oedema, thought to be due to mild congestive failure, disappeared, in spite of the tendency to sodium retention with this drug.

A biopsy specimen from the skull, taken during cortisone therapy, showed a relative absence of osteoclasts and extremely active osteoblasts. The authors' interpretation of their interesting observations is that ACTH and cortisone, perhaps by their anti-inflammatory effects, suppress the destructive process in bone in Paget's disease, leaving bone production temporarily unopposed. The result of this is a transitory fall in the urinary and serum calcium which persists while bone production is in ascendancy. However, bone repair soon diminishes to match the decreased rate of destruction, and the urinary and serum calcium again rise. The alkaline phosphatase tends to fall as the urinary calcium returns to the control values, paralleling the diminished osteoblastic activity.

The authors emphasized that this was one possible interpretation; others were being considered. Further studies are needed to test the hypothesis and to explore the possible therapeutic value of these drugs.

Dr. J. Vernon Luck [31] pointed out that these studies emphasize the importance of avoiding immobilization in the treatment of fractures in Paget's disease. He expressed some doubt as to the authors' concept of the osteoblastic phase being purely reaction to stress. He emphasized that Paget's disease, except in the skull, shows a predisposition for areas of greatest mechanical stress; yet the bizarre mosaic pattern of bone formation is obviously not influenced by the lines of stress, as would be expected if this were purely reaction to stress.

Dr. H. Herman Young [32] emphasized the dangers of prolonged use of ACTH and cortisone, citing cases in which death from adrenal insufficiency followed the surgical procedure.

Dr. J. Albert Key [16] pointed out that loss of calcium with immobilization is not peculiar to Paget's disease; it occurs, as he had observed, to a significant degree in normal bone, especially in children. He asked for the rate of turnover of calcium in normal bones as compared with that in bone in Paget's disease.

Dr. William T. Green [15] remarked on his experiences with vitamin-D-resistant rickets in which dangerous degrees of calciuria and very high levels of serum calcium and phosphorus resulted after surgery and immobilization unless the maintenance dose of vitamin D was reduced.

In closing, Dr. Henneman stated that, although there was no way of comparing the rate of turnover of calcium in normal bone with that of bone in Paget's disease, Dr. Albright considered it to be as much as a hundred or a thousandfold in bone in Paget's disease as compared with that in normal bone.

The Management of the Tuberculous Hip Joint. In a stimulating presentation Prof. Walter Mercer [17] discussed the great changes which have developed in the management of the tuberculous hip joint since the introduction of antibiotics. He contrasted the frequent terrible deformities and high over-all death rate of the earlier methods of treatment with later improvement in treatment climaxed by the introduction of antibiotics. This has altered our approach to the problem, since we now have better control of the disease. He found that in Scotland most tuberculous hips, which had formerly occurred in the first five years of life, now occurred five or ten years later. He felt that improved economic conditions, nutrition, housing, and milk control were important factors and that vaccination of children with Bacillus Calmette-Guérin will have a definite effect in reducing the incidence of joint tuberculosis. He stated that in a recent study of 950 patients with skeletal disease, 26.3 per cent. had bovine tuberculosis and 73 per cent. had human tuberculosis, whereas formerly bovine infection had been five times more common.

Prof. Mercer emphasized the importance of early diagnosis, since the prognosis is so improved by chemotherapy that there is a reasonable chance of obtaining a mobile hip joint if the disease is recognized in the early synovial stage. He recommended a biopsy of the deep inguinal glands, if there is bone atrophy as seen by x-ray, and stated that from the point of view of diagnosis this is more important than arthrotomy, since the bacilli are filtered to the glands and are more likely to be found. If the biopsy specimen from the glands reveals bacilli, the diagnosis is settled; arthrotomy may still be considered if there is any doubt. He stated that biopsy of the synovial membrane is done more and more and that it is safe under antibiotic cover. He quoted McKenzie's comment that the old "wait-and-see policy" has become a policy of "look and see". He emphasized that arthrotomy is even more important for relieving the tension on the joint with its effects on the blood supply than it is for diagnosis. Local obliterative endarteritis is one of the main features of skeletal tuberculosis; this interferes with antibiotics reaching the part unless the part has been opened surgically. Synovectomy affords an opportunity for a healthy membrane to be developed along with fresh blood vessels which will bring the antibiotic into the diseased area.

Chemotherapy has allowed us to return to the more radical methods of local surgical attack, some of which were formerly disappointing because of sinus formation and spread of the disease. He emphasized, however, that a tuberculous hip is a metastatic manifestation of the disease and that sanitarium regimen is still imperative.

He stressed the importance of the antibiotics, and felt that his group was perhaps more optimistic than men are in the United States regarding the future of skeletal tuberculosis, stating that now, in early cases, we may hope for a mobile joint, and, in older cases, a shorter period of immobilization, an earlier and quicker

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[32] Mayo Clinic, Rochester, Minnesota.

fusion, and fewer complications. He emphasized the importance of using a combination of three drugs, streptomycin, sodium para-aminosalicylate, and isoniazid, the latter being the only one so far capable of entering macrophages or phagocytes. Our agents are most efficient in the early stages, and cases of hip-joint disease are seen comparatively late. One of the primary objectives of the surgeon is to give the chemotherapeutic agents access to all diseased areas as early as possible. He discussed the combination of streptomycin sulphate, one gram daily, with sodium para-aminosalicylate, five grams four times a day; streptomycin sulphate, one gram daily, with isoniazid, 100 milligrams twice a day; and isoniazid, 100 milligrams twice a day, with sodium para-aminosalicylate, five grams four times a day. He felt that with any one of these combinations resistance to the drugs should be very low. He was strongly in favor of really prolonged chemotherapy; and, while he thought that a year was a reasonable minimum period of time to continue with treatment, he would ordinarily prefer to continue chemotherapy for at least three months after the local lesion had become quiescent and well under control. If combinations involving streptomycin had been used for six months or so, he would switch to a combination of isoniazid and sodium para-aminosalicylate to save the patient so many injections, but under no circumstances should any of these drugs be used alone. Streptomycin twice a week, with isoniazid daily, was felt to carry a considerable risk of the development of isoniazid resistance.

He considered the treatment of the three types of tuberculous hip-joint involvement. In the treatment of the *extra-articular focus*, he recommended early excision of the lesion, under antibiotic cover and the filling of the cavity with cancellous-bone chips, as well as the use of streptomycin and penicillin powder locally, in the expectation of a complete reconstitution of the bone and a mobile hip.

In *synovial disease*, with a tense full joint and with the synovial membrane and the capsule ballooned out by an effusion, a mobile joint can be obtained if the streptomycin and other drugs can reach it in a sufficient concentration and if the joint surfaces are undamaged. In this type, early biopsy and decompression are justified, not only for purposes of diagnosis but also in order to relieve tension and to allow the penetration of the chemotherapeutic agents. As much as possible of the diseased synovial membrane, with part of the capsule, should be removed. The synovectomy permits formation of fresh normal synovial tissues, carrying young blood vessels through which the antibiotics can circulate freely. Only skin traction is necessary for immobilization.

In the *intra-articular lesion*, if the *articular cartilage is still intact*, he feels that there is the possibility of obtaining a mobile hip, at least for many years. After eradication of the diseased area in Babcock's triangle, or the acetabular region, packing with cancellous-bone chips and the use of penicillin and streptomycin powder, followed by a few weeks' plaster immobilization (in the case of femoral foci) or fairly heavy traction (in the case of acetabular foci), many patients will have mobility and may not require arthrodesis at a later stage. Prolonged chemotherapy is important. If *articular cartilage is damaged*, in late cases, bony fusion is necessary after the patient's general resistance, aided by chemotherapy, has been built up to overcome the general toxaemia of the bacillary invasion. Prof. Mercer prefers the Brittain arthrodesis. He uses an open posterior approach which allows identification of the sciatic nerve, open inspection of the joint, relief of intra-articular tension, and removal of necrotic debris.

In the case of tuberculous abscess, he felt that aspiration or incision should be done as soon as possible in order to relieve the tension which causes thrombosis and a delay in healing.

If sinuses do not heal with local and general antibiotics, surgery may be indicated for the removal of old thick-walled sinus tracts or sequestra.

In concluding, Prof. Mercer felt that chemotherapy in tuberculosis has been in use long enough for us to accept it as the most useful adjunct to surgery, the principles of which must be modified and advanced in order to utilize fully the properties of the drugs. Antibiotics shorten the course of the disease; thus long rigid immobilization is probably no longer essential and renal calculi, osteoporosis, and premature epiphyseal closure with extremity-shortening are eliminated. He expects the development of further chemotherapeutic agents of greater bacteriostatic and penetrating properties, which together with further advanced surgical treatment will result in more mobile hips.

Since most tuberculous lesions heal by fibrous tissue or recalcification without regeneration of the original tissue, osteo-arthritis is likely to occur and arthroplasties will have to be done later.

In the advanced intra-osseous type of lesion, bony ankylosis must still be our aim and its achievement the method of choice. Now, more than ever, we must strive for early diagnosis by biopsy and the concomitant decompression of a tuberculous hip joint in order to obtain a mobile hip.

A Study in the Efficacy of Iproniazid Versus Isoniazid in the Treatment of Bone and Joint Tuberculosis. Dr. David M. Bosworth [33], Dr. J. William Fielding [34], Dr. Hudson Wilson [35], Dr. Manuel Guzman Acosta [36], and Dr. L. M. Demarest [37] reported their clinical study of the relative efficacy of isoniazid and

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iproniazid in the treatment of bone and joint tuberculosis. Their observations of twenty-nine patients form the basis upon which they have compared these two drugs. Six patients with active pulmonary lesions, none of whom were seriously ill, had no active tuberculous bone or joint disease, although in two patients there were arrested tuberculous joint lesions. The authors reported that they had included this group for purposes of comparison with the group of patients with bone and joint tuberculosis. The group was followed for an average of 13.5 months and made a gain which was estimated by the authors at 25 per cent. of complete recovery on an average dose of isoniazid of 8.2 milligrams per kilogram of body weight. Five of the six patients are still under treatment. There was an average weight gain of 22.3 pounds; the chest lesions completely healed in two patients, were moderately improved in two patients, and remained unchanged as seen roentgenographically in two patients. All of the patients in the group "did well", but in no instance was the improvement dramatic. In a second group, there were five patients, clinically not severely ill; two of them showed spinal tuberculosis, one had tuberculous osteomyelitis of the ulna, one had a tuberculous lesion of the fascia of the thigh, and one had meningitis (the latter had previously received an intensive course of streptomycin over a period of six weeks without definite evidence that the disease process was being controlled). In none were there sinuses. Followed for an average of 11.2 months, the patients in this group made a gain, in respect to general improvement, which was estimated by the authors at about 25 per cent. of complete recovery on an average dose of isoniazid of 5.8 milligrams per kilogram of body weight. One patient, with fascial disease of the thigh, appeared to be completely healed; all were improved. However, in four, control of the disease was incomplete. In a third group, there were seventeen patients, all of whom were seriously ill. The patients were treated with isoniazid and later with iproniazid. Two of the patients had spinal tuberculosis and paraplegia, four had spinal tuberculosis without paraplegia, one had tuberculous meningitis, and one had tuberculous involvement of the wrist.

Three died,—two with spinal disease, paraplegia, and ascending kidney infection, and one with tuberculosis of the wrist and uncontrollable pulmonary hemorrhages. Of the fourteen survivors, five were without sinuses and nine had one or more sinuses. No sinus healed during isoniazid therapy; in seven of nine patients the sinuses healed completely while iproniazid was being administered. There was marked improvement but incomplete healing of the sinuses in two patients.

Isoniazid was used for an average period of seventy-eight days; iproniazid for an average of 170 days per patient. Improvement during the administration of isoniazid was estimated by the authors at about 25 per cent. of complete recovery, while the gain made during iproniazid therapy was almost 50 per cent. of complete recovery. Under iproniazid therapy, sinuses healed in an average of sixty days as contrasted with the lack of healing of sinuses during seventy-eight days of isoniazid therapy.

The average dose of isoniazid was 3.6 milligrams per kilogram of body weight; the average dose of iproniazid was 2.8 milligrams per kilogram of body weight. The average gain in weight in patients treated with isoniazid was 4.3 pounds; in patients treated with iproniazid, the average gain in weight was 16 pounds.

There were three instances of minor neurotoxic reaction during isoniazid therapy; there were five minor and one mild instances of neurotoxic reaction during iproniazid medication. There were no psychoses and no evidence of permanent functional liver damage.

From these few cases the authors conclude that iproniazid is "much more effective" and that its "toxicities can be adequately controlled".

In discussion, Dr. Robert W. Johnson, Jr. [38], declared that he was perfectly willing to accept the clinical evaluation of iproniazid but that his vote of confidence rested on his faith in Dr. Bosworth's experience and clinical judgment rather than on a frank acceptance of the facts as presented. He felt that there were too few cases; these were not sufficiently controlled to justify the conclusion that the results were statistically significant.

Mr. J. C. Scott [39] felt that the comparison was an extremely difficult one to make; to make it bear statistical scrutiny was difficult in the extreme. He felt, as Dr. Bosworth did, a firm confidence in the antibiotics, but he had not been able to marshal convincing evidence in support of his enthusiasm because there were too few cases followed for too short a time. He felt the ideal antibiotic had not yet been found, but, if it is discovered, it would be one which would not interfere with the development of the patient's resistance and the improvement in his general condition; nor would it be one which in any way increased the resistance of the organism. He concluded with a most apt quotation, "If a man builds a better mousetrap, nature will soon produce a smarter mouse".

Dr. Alan DeForest Smith [40] introduced a further word of caution with regard to drawing conclusions about comparison of results of isoniazid with those from iproniazid when sufficient controls are lacking. He had not been able to detect any outstanding difference in the reaction to the two drugs when he had given them to alternate cases in a series of thirty; both had apparently been quite effective. He warned against interpreting the improvement in the patient's general condition as an indication of improvement in the local lesion.

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In the closing discussion, Dr. Bosworth pointed out that he had made it quite clear that his paper was a one-year follow-up report and that the work was in too early a stage for statistical analyses.

Plastic Flat-Foot Operation—Thirty-Year Follow-up Study. After further experience with the method and with follow-up studies over a thirty-year period, Dr. Oscar L. Miller [41] again reported on his operation for painful weak foot which was first described by him in 1927.

The author had reviewed his cases over a period of thirty years. The results substantiated his claims and amply justified his confidence in the method.

The procedure has remained essentially unchanged. There is now, however, one slight modification. Whereas formerly both the naviculocuneiform and cuneiform-first-metatarsal joints were included in the remodeling and fusion, he now does this exceptionally and then only in case the foot is extremely pronated, flattened, and in the valgus position. Usually the operation is performed as previously described except that the naviculocuneiform joint alone is excised after the osteoperiosteal flap has been raised in the manner originally reported. The osteotomies are performed on either side of the joint so that the valgus position and the long arch depression are corrected. Great care is exercised in reshaping the foot, and, at the close of the operation, if it has been done properly, the foot will assume the correct shape. Chip grafts, taken from the excess bone of the medial portion of the navicular, are used where needed in the region of the excised joint.

Plaster fixation is fashioned meticulously in order to maintain the proper shape and position of the foot. The calcaneus and the metatarsals must be in the neutral position; overcorrection must be avoided. Attention to these details is indispensable. The first plaster cast is worn without weight-bearing for four to five weeks. A well molded walking cast is then worn for six to eight weeks. Oxfords and arch supports are worn for one year.

Section of anomalous bone and anterior or posterior tibial-tendon procedures may be performed if the surgeon so desires. A tight tendo achillis must be overcome, in the author's opinion; otherwise the reconstruction will fail.

Further Experience with Extra-Articular Arthrodesis of the Subastragalar Joint. Dr. David S. Grice [42] reported an evaluation of the operative procedure which he had devised to correct deformity, to restore the height of the foot, and yet not to interfere with growth of the foot in young children. Thus, this operation makes possible the surgical treatment of young children, with paralytic flat feet, who would otherwise have to wait until they are old enough for a triple arthrodesis. The report is based on his experience with fifty-two paralytic flat feet resulting from poliomyelitis. Thirty of the children were between four and eight years of age. He considers the operation indicated in the young child with uncontrollable and increasing pes valgus, with lateral displacement of the calcaneus on the talus. He believes that the operation can be successfully performed upon the young child, that correction of the deformity can be maintained, and that the growth of the foot is not interfered with. In the technique of the operation, two small corticocancellous grafts are taken from the tibia of the same limb and are inserted with particular care in the sinus tarsi after the deformity has been corrected. The two grafts are so placed that they lie in a plane at right angles to the axis of motion of the subtalar joint, with cancellous surfaces apposed. The pointed ends of the grafts are countersunk through the thin cortex of the talus and calcaneus (a minimum of cortex being removed to facilitate the penetration) as the inverted foot is moved toward eversion until it is in the neutral position. This should lock the grafts in place. It is worthy of notice that any fixed equinus deformity should be corrected at, or before, the operation and that, with muscle imbalance, transplantation (done in forty-four cases) of available muscles is necessary either to support the talonavicular area or to give better function to the foot.

The longest period of follow-up was nine years; there were twenty-three patients who had been followed for at least three years; fourteen had been followed for two years, and fifteen, between one and two years.

The results have been classified as *good* or as a *complication*, the latter being primarily a failure of correction of the deformity at the time of the operation or an overcorrection. There were forty-one good results. In seven patients, there was insufficient correction; in four, there was overcorrection. In only three patients was there any difficulty in obtaining union.

The author mentions that this procedure has been performed in the treatment of deformities due to conditions other than poliomyelitis. This further experience by the author with the operation and the longer follow-up period of his cases demonstrates the value of the operation on paralytic flat feet resulting from poliomyelitis, especially in that age group in which triple arthrodesis is contra-indicated because of age. As with other procedures performed in childhood, further evaluation as the patient grows will be necessary.

Wednesday, June 9, 1954

Prognostic Implications of Electromyography in Acute Anterior Poliomyelitis. Dr. Helge Hertz (deceased), Dr. Annelise Madsen [43], and Dr. Fritz Buchthal [44] reported that the final degree of paresis is

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determined early in the acute stage of anterior poliomyelitis. In a repetition, with improved technique, of previous studies, forty-five patients (90 per cent. of whom were under the age of fourteen) treated in the Orthopaedic Department of the Children's Medical Center, Boston, in the summer of 1952, were subjected to electromyographic examinations during the initial stage of the disease and one year later. The normal muscles of 130 normal subjects served as controls. In the acute stage of the disease, the mean action-potential duration was 30 per cent. greater in the severely paretic muscles which one year later did not show signs of recovery than it was in normal muscles. Muscles with an equally severe paresis during the acute stage but which showed one year later a great deal of improvement presented normal values of mean action-potential duration. Muscles with a less severe paresis but with no recovery or only slight recovery also had mean action-potential duration within normal limits. One year after the initial stage, all of the affected muscles, irrespective of the degree of recovery, disclosed an increase in mean duration which averaged 20 to 30 per cent.

The mean action-potential amplitude recorded during the acute stage of the disease was within normal limits for all groups. One year later, it had increased by 50 to 150 per cent., regardless of the degree of recovery.

Fibrillation potentials occurred in 62 per cent. of all paretic muscles in the acute stage of the disease; fibrillation potentials occurred in only 35 per cent. one year after the initial stage of the disease. Earliest signs of denervation were found thirteen days after the onset of the disease in acutely paretic muscles which later recovered only slightly or not at all. In these muscles, fibrillation potentials occurred more frequently (75 per cent.) than in the severely paretic muscles which showed good recovery (33 per cent.). Synchronous activity between different leads in the same muscle was clearly correlated to the degree of recovery. It occurred in 40 per cent. of paired leads in severely paretic muscles which did not recover, examined in the initial stage, as compared with 20 per cent. in the other groups and in the normal controls.

Intramuscular temperatures were measured and an average temperature of 35.4 degrees centigrade was found in the severely paralyzed muscles which later did not recover as compared with the temperature of 36.3 degrees centigrade in all of the other groups. One year later the temperature readings disclosed the same tendency to be lower in the paretic muscles.

The finding of a definite correlation between muscle action-potential characteristics, on the one hand, and the degree of recovery, on the other, indicates that the eventual outcome of the muscle paresis is largely determined by the initial disease process. Electromyographic studies early in the disease may thus provide a useful guide as to which muscles will and which will not benefit by physical therapy or other methods of treatment directed to the muscles.

This paper is published in full in this issue of *The Journal*, pages 902–911.

Two-Joint Muscles of the Thigh. Dr. J. E. Markee [45], Dr. John T. Logue, Jr. [46], Dr. M. Williams [47], Dr. W. B. Stanton [48], Dr. R. N. Wrenn [49], and Dr. L. B. Walker [50] presented a study restricted to those muscles which act over both the hip and the knee joint; these muscles being the rectus femoris, the semimembranosus, semitendinosus, the biceps femoris, the sartorius, and the gracilis. The standard concept of the actions of these muscles as presented in textbooks of anatomy was reviewed. The authors pointed out that their study disclosed that many aspects of the action of these muscles could not be explained by the conventional concept of their function. This investigation was divided into two parts,—the first part consisting of morphological studies of the muscles previously mentioned in the human subject and the second part representing functional studies in the dog. In the morphological studies, the nerve supply was meticulously investigated, together with the character of the muscle fibers throughout the course of the muscle. Functional studies, which were limited to the dog, were carried out in anaesthetized dogs which were either subjected to spinal transection or prepared for cortical stimulation. It was found that movement at two joints could be produced simultaneously by all of the muscles of the thigh which pass over two joints; likewise, movement at one joint only could be produced by all of the thigh muscles. This is contrary to the contemporary concept which postulates that the muscles in the thigh which act over two joints must produce motion at both the hip and the knee joints, unless other muscles are brought into play to prevent movement at one of the joints. Evidence was presented which indicated that movement at the hip without movement at the knee could be produced by each of these muscles,—that is, the rectus femoris, the sartorius, the gracilis, the semitendinosus, the semimembranosus, and the biceps femoris; movement at the knee without movement at the hip could be produced by the gracilis and the biceps femoris.

Most of the tension created in the movement at two joints was transmitted by tendons to bony attachments; most of the tension resulting in movement at a single joint was transmitted to the fascia. The study

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[49] Duke University School of Medicine, Durham, North Carolina.
[50] Duke University School of Medicine, Durham, North Carolina.

indicated that the fascial anchorage played an extremely important part in the segmental function of the muscle.

Eccentric contraction of the parts of these muscles, which acted over two joints, facilitated coordinated simultaneous movements at both the hip and the knee joints.

Muscles which act over two joints were found to be ideally arranged to participate in certain kinds of force couples. The raising of the body weight from a chair was studied, and it was noted that some of the tension produced by the quadriceps femoris was used by the hamstrings to extend the hip joint even when the hamstrings were not shortening. Prevention of excessive gliding at the knee appeared to be one function of the two-joint muscles.

While functional studies were not carried out on human subjects in this investigation, it seemed entirely reasonable to apply the findings in the functional studies of the dog to an interpretation of muscle function of the two-joint muscles in the human being.

Electron Microscopic Studies of Muscle. Dr. David Spiro[51] briefly reviewed present-day knowledge of the macromolecular structure of muscle as it is revealed by the electron microscope. The work presented was primarily that of Huxley and Hanson with contributions by Hodge, Hall, Jakus, Schmitt, and Spiro. Dr. Spiro outlined some of the biochemical reactions occurring in muscle, pointing out that for some time it has been known that muscle contraction is attended by the splitting of adenosine triphosphate (ATP) into adenosine diphosphate (ADP) + PO_4 with the liberation of energy. This reaction presumably furnishes the energy for muscle contraction. Two major contractile proteins in muscle have been characterized by a number of workers and are known as actin and myosin. These two proteins undergo reversible association depending on the presence or absence of ATP.

In the light microscope, striated muscle fibers appear as long, multinucleated cells, packed with myofibrils in parallel array, which run the length of the cell. The myofibrils are axially differentiated into more dense A bands which are birefrigent (or anisotropic under polarized light) and alternate with less dense I bands which are non-birefrigent or isotropic. The center of the A band is somewhat less dense than the remainder of it and is known as the H band. In the center of each I band is located the fine Z membrane. The portion of the myofibril between two adjacent Z membranes is known as a sarcomere, which consists of an A band in its center plus the halves of two adjacent I bands. When muscle contracts, the sarcomere shortens. With the electron microscope, structural details of fragmented isolated myofibrils can be made visible. These fibrils are composed of parallel filaments which present a periodic structure, each segment of which is about 400 Angstrom units in length. There are some sixty of these segments in a single sarcomere.

With recently developed techniques of cutting ultrathin sections, it has been possible to obtain further insight into the macromolecular structure of the myofibrils. It is now possible to examine intact muscle in preparations sufficiently thin to permit good definition of both transverse and longitudinal sections of the muscle cells. This has revealed the Z membranes to be continuous across the muscle fiber between adjacent myofibrils. Mitochondria are visualized as round or oval bodies located between myofibrils. They also display a high degree of structure. These bodies are responsible for the energy-producing reactions of the muscle cells (such as the synthesis of adenosine triphosphate) and are most numerous in the more functionally and metabolically active muscles such as the myocardium and the flight muscles of insects. Huxley showed that cross sections of myofibrils vary in appearance, depending upon which portion of the sarcomere has been sectioned. Sections through the H band (in the center of the A band) reveal a simple hexagonal array of fairly large filaments (that is, each filament is surrounded by six close neighbors) about 140 Angstrom units in diameter and spaced 200 to 300 Angstrom units apart. Sections through the remainder of the A band (exclusive of the H band) disclose a remarkable compound array consisting of two different types of filaments. The larger filaments seen in the H band are again present here, but in addition smaller filaments (measuring about 40 Angstrom units in diameter) are seen lying symmetrically between three of the larger ones. Therefore, there exists here the simple hexagonal array of larger filaments, plus six small filaments surrounding each large one. Sections through the I band reveal only disorganized thin filaments and no thick ones. More recently Huxley and Hanson have shown that extraction of the myosin by chemical methods results in the removal of the thicker filaments leaving the thinner ones behind. It is the belief of these workers that the thicker filaments are myosin, while the thinner ones are actin. At present their concept of the structure of the myofibril is as follows: The I band is composed of actin filaments which are continuous through the A band up to but not including the H band. The A band contains myosin filaments throughout its length. Therefore, there are both actin and myosin filaments present in the A band, exclusive of its H region, and only myosin in the H band. The actin filaments in the A band can only be seen in muscle from which the ATP has been extracted. The most probable explanation of this is related to the influence of ATP on the interaction of actin and myosin.

Now that knowledge of the macromolecular architecture of striated muscle has been advanced to this extent, we are in a position to attempt an elucidation of the contractile mechanism itself. Indeed, such experiments are now in progress.

[51] Department of Biology, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Immunization in Poliomyelitis. Dr. Hart E. Van Riper[52] presented a very comprehensive review of the present status of the vaccination program in poliomyelitis. He summarized the previous attempts to control poliomyelitis by vaccines which proved ineffectual because of the lack of our present knowledge of tissue-culture techniques, virus typing, and the existence of viraemia in affected individuals. Dr. Van Riper pointed out that the present field trials with the Salk vaccine have been made possible because of the development of a new tissue-culture technique by Dr. John F. Enders in 1949, which ended the total dependence on monkeys as experimental tools. Likewise, the completion in 1951 of virus typing and the identification of three immunologically independent virus types (Brunhilde, Lansing, and Leon) made possible the development of a polyvalent vaccine. At the present time no other pathological poliomyelitis virus has been identified, although it is conceivable that a fourth or fifth type may be found some time in the future. The recognition in 1952 by Dr. Bodian that a viraemia occurs in the prodromal stages of the disease, before invasion of the central nervous system, has stimulated the present vaccine trials.

The present field trial in the use of poliomyelitis vaccine is being conducted in 217 selected test areas in forty-four states in the United States and in additional areas in Canada and in Finland. Two types of observed groups are being used in this nationwide and international study: (1) in the so-called placebo control areas, ninety-one in number, half of the children in the first three grades in school receive vaccine and half a placebo and (2) in the so-called observed control areas, 126 in number, children in the second grade in school receive vaccine injections while the children in the first and third grades receive no injections. The routine vaccination schedule includes three inoculations of one cubic centimeter each of the Salk vaccine in the left triceps muscle. The second injection is given one week after the first, and the third inoculation four to five weeks after the second. In children receiving the placebo injections, the same routine is followed. At the evaluation center at the University of Michigan under the guidance of Dr. Thomas Francis, the code distinguishing between vaccine and placebo inoculations is known; it is known nowhere else.

Before the poliomyelitis season of 1953, Dr. Salk had administered the vaccine to approximately 600 persons. The facts that of the 474 children between the ages of four and twelve inoculated none contracted poliomyelitis in 1953 and that seven were known to have been exposed to the disease were considered to be interesting, although obviously not significant.

In contrast to the 1951 and 1952 controlled experiment of passive immunization against poliomyelitis with the use of gamma globulin, in which it seemed apparent that a temporary immunity was given from six to eight weeks, it seems likely or rather possible that vaccine inoculations may give a much longer period of immunity, but it will take years to learn how long the period of immunity actually lasts. It also seems likely that contact with the virus may increase the antibodies without paralytic poliomyelitis developing in the individual himself.

All children in this vaccine study in whom paralytic poliomyelitis develops will be followed in a routine manner by standardized examinations for muscle involvement. The first examination will be made ten to twenty days after the onset of the disease and the second examination, fifty to seventy days after the onset of the disease. Thorough clinical and epidemiological records will be made in every reported case of poliomyelitis in this group, including a study of the family in each case.

Dr. Van Riper states that it is appreciated that, while the vaccination may prevent access of the virus to the nervous system by way of the blood stream, nevertheless, it is possible that the central nervous system may be involved through extension along the nerve trunks. The development of paralytic poliomyelitis, even under these circumstances, may be prevented by a spill-over of vaccine-induced antibodies from the blood into the nerve tissue.

Justification for the vaccine trial is based on the fact that the statistics in the United States show that the possibility of acquiring paralytic poliomyelitis between birth and the age of twenty is about one in 153. If the vaccine is proved to be only 50 per cent. effective, it will still be worth while.

The final evaluation of the vaccine trial will be made by the Poliomyelitis Vaccine Evaluation Center at the University of Michigan under the direction of Dr. Thomas Francis. A report of the results may be expected in 1955, and this report will determine, in all probability, the future use of the vaccine.

Dr. Van Riper presented an excellent review of the extensive work done in the prevention of poliomyelitis in the past and of the many possible significant results which may follow this 1954 immunization trial with the use of the Salk vaccine. It is recommended that this paper (published in full in this issue of *The Journal*, pages 893–901) be read by all physicians interested in poliomyelitis, especially pediatricians and orthopaedic surgeons.

Fixed Pelvic Obliquity—A Study of a New Approach. In this paper, which was frankly a preliminary study, Dr. George J. Garceau[53] and Dr. Edward Gilette[54] confined their attention to that type of deformity caused by muscle imbalance above the iliac crest. In monkeys, experimental neurectomy of the twelfth thoracic and first lumbar roots on one side had resulted in the production of a scoliosis. The curve,

[52] The National Foundation for Infantile Paralysis, Inc., 120 Broadway, New York, N. Y.
[53] 23 East Ohio Street, Indianapolis 4, Indiana.
[54] Riley Hospital, Indianapolis, Indiana.

as was to be expected, was convex on the side of the operation. Anatomical studies showed the innervation of the internal and external oblique abdominal muscles to be from the sixth thoracic to the second lumbar segments, and of the quadratus lumborum to be from the twelfth thoracic to the third lumbar segments. Since, in a well developed case of fixed pelvic obliquity, there is a contracture of the trunk muscles on the concave side of the curve and since it is impossible to overcome this contracture by actual division of the involved muscles, it would seem logical to diminish their strength by division of their motor nerves.

Thirteen patients have been treated by neurectomy. Thus far, the twelfth thoracic and first and second lumbar motor nerves have been sectioned after a suitable laminectomy. Ten days postoperatively, a corrective plaster corset was applied. To test the validity of the method, no fusions or fascial transplantations were performed. Thus far, aside from a sensory loss, there have been no unpleasant sequelae,—all of the patients are improved in appearance and in their ability to sit and walk.

Experiments have been conducted on dogs to determine how many nerve roots may be cut with impunity. Three seems to be the limit since, if more are sectioned, vascular changes result. Roentgenograms were shown which revealed some improvement in the degree of curvature.

Clinical Evaluation of Freeze-Dried Bone Grafts. Capt. Chalmers R. Carr [55] and Lt. Comdr. George W. Hyatt [56] reported on the clinical use of freeze-dried preserved bone. This material has been used in 125 patients by fifteen different surgeons. The bone used in grafting procedures in these cases was obtained by postmortem surgical procedures. It was then freeze-dried and was stored in sterile containers at room temperature. The authors report that this method of preserving the bone has proved quite satisfactory, that it may be shipped without difficulty, and that it requires no special apparatus for storing. Apparently there is no time limit on how long it may be stored. The rejection rate from bacterial contamination is listed as 8 per cent.

Of the 125 cases, they were able to follow ninety-nine, with an average follow-up period of five to thirty-six months. There were eighty-four surgical successes and fifteen surgical failures. The authors broke this down further and felt that, in six cases, failure could be related to surgical procedures and not related to the graft itself; nine were related to the graft.

Eighteen of the patients operated upon had infection prior to surgery. In three of these infection developed postoperatively. There were three instances of wound infection in previously non-infected patients.

The authors felt that the study indicates that freeze-dried bone compared quite satisfactorily with autogenous bone and is a satisfactory substitute for autogenous bone grafts.

In discussion, Dr. Philip D. Wilson [57] pointed out the value of this type of preserved bone for use in the military services. He considered the authors' rate of failure of 9 per cent. to be very good, but he thought that with longer follow-up and more cases the results would probably not be as satisfactory. His own series had shown a 15 per cent. rate of failure. He noted that, in order to be successful, the homogenous graft must be in contact with the host bone throughout its entire length.

Dr. Robert D. Ray [58] discussed the functions of a bone graft. Under proper experimental conditions, synthetic calcium salts will serve as a lattice for new-bone formation, while frozen bone will grow in tissue culture after many months of refrigeration. He noted that in the present state of our knowledge we really do not know what should be preserved. Should it be the cells, the matrix, or the calcium salts?

Dr. Charles H. Herndon [59] pointed out that although homogenous grafts are revascularized almost as rapidly as are autogenous transfers and that as seen by x-ray the results may be analagous for months, resorption and new-bone formation is long delayed in the homogenous grafts, at times for years, due probably to protein specificity and immune reactions. Eventual disintegration of the graft is common. He feels that the method of bone preservation which the authors have developed is a valuable contribution.

The Presidential Address "Responsibility and Research in Orthopaedic Surgery" by Dr. A. R. Shands, Jr. [60], was published in full in the July issue of *The Journal* (pages 695–703).

Thursday, June 11

The Place of Nerve-Grafting in Orthopaedic Surgery. Mr. Donal Brooks [61] gave an excellent presentation of this difficult problem based on the experiences in ninety-three patients operated upon during the past twelve years by Mr. Seddon and his associates at the Royal Orthopaedic Hospital. The method is indicated when a gap between the nerve ends is too large to be bridged by direct suture, when there is a partial lesion with a lateral neuroma, or when there are extenuating circumstances, such as a concomitant tendon suture which demands early mobilization.

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[56] United States Naval Hospital, Bethesda, Maryland.
[57] 321 East 42nd Street, New York 17, N. Y.
[58] University of Washington, Seattle 5, Washington.
[59] 2065 Adelbert Road, Cleveland 6, Ohio.
[60] Rockland Road, Wilmington, Delaware.
[61] Royal National Orthopaedic Hospital, 234 Great Portland Street, London W. 1, England.

In general, the same technical rules apply to nerve-grafting as to direct nerve suture. The cross section of the graft must equal that of the injured nerve. The graft must be 12 to 15 per cent. longer than the gap between the nerve ends to allow for shrinkage. As a source for the graft, sensory nerves are usually used; occasionally, a complete nerve, such as the ulnar nerve, is used to graft a more important nerve, such as the median nerve.

The types of nerve grafts may be single, as in the repair of digital nerves, inlay grafts, cable grafts, or pedicle grafts. Plasma clot is used for single grafts or in some inlay grafts to "glue" together the nerve ends along the suture lines. In the pedicle graft, designed by St. Clair Strange, the proximal stump of the median nerve is swung upward and inward so that it may be sutured to the proximal stump of the ulnar nerve. After union of the two nerves has resulted, the ulnar nerve is divided close to the axilla at a point where the cut end will reach to the distal end of the median nerve. This operation has given favorable results in the five patients in whom it has been employed. In the other types of grafting, there has been recovery in about 50 per cent. of the cases.

In the discussion Dr. Eric Moberg [62] referred to a new type of graft which has been successful in his hands. This consisted in the total transfer of the skin of the ulnar portion of the palm and of the fourth and fifth fingers, including the ulnar nerve, to the radial side of the hand. The ulnar stump was sutured to the median nerve and the skin flap was sutured to the thumb and index fingers.

Dr. Barnes Woodhall [63] injected a note of discouragement based on the often indifferent results from peripheral-nerve surgery in our Armed Forces during World War II. He made a strong plea for careful weighing of the possibilities of tendon transplantation before one decides on nerve suture or nerve grafting. Of 513 median-nerve sutures, performed at various times after gunshot wounds, only 50 per cent. of the cases showed any power in the abductor pollicis brevis; of the 50 per cent. which could contract against resistance, there was a restoration of only 15 per cent. of the normal by dynamometer. Of 741 ulnar-nerve sutures, only 49 per cent. showed contraction against resistance in the abductor digiti quinti and first dorsal interosseus, but in these the dynamometer disclosed a restoration of only 13 per cent. of the normal. While these data do not take into consideration more recent advances in peripheral-nerve surgery, Dr. Woodhall still leaned in general toward orthopaedic measures rather than nerve grafting. With regard to restoration of sensation, he was fully in accord with Mr. Brooks. Regarding the defensive sensations of pain and touch, 75 per cent. of the patients subjected to median-nerve surgery regained these sensations.

The Significance of Lumbodorsal Changes in Low-Back Pain. Dr. Ian Macnab [64] presented evidence to show that pain in the low back may have its origin in the thoracolumbar region. He cited the work of Kellgren, that of Inman, Saunders, and their coworkers, and his own similar experiments. He had injected hypertonic saline solution into the thoracolumbar junction, thus producing referred pain. There was spreading both cranially and distally, but most commonly the pain was referred to the region of the iliac crest. Occasionally, it was felt as low as the base of the greater trochanter. In an attempt to ascertain the clinical significance of this finding, the author analyzed the distribution of pain in fifty patients with fractures of the spine between the tenth thoracic and the first lumbar levels. Twenty-one had immediate or residual low-back pain. All of three patients with pyogenic osteomyelitis involving this level had low-back pain, and one patient with a tumor of the second lumbar vertebra had a presenting symptom of pain in the buttocks, spreading to the lateral aspect of the greater trochanter.

In an attempt to determine whether or not similar symptoms arise from the degenerative changes which commonly occur at the thoracolumbar level, two tests were employed clinically: (1) the finding of tenderness to firm pressure over the spine between the eleventh thoracic and first lumbar vertebrae with the patient in lateral decubitus position, with the knees flexed against the chest to fix the lumbosacral spine, and (2) the elimination of the patient's low-back pain by infiltration of this tender or trigger area with 1 per cent. novocain. The author's experience indicated that these tests were positive in a sufficient number of patients to suggest that degenerative changes and spinal ligamentous injuries in this region can in fact cause referred low-back pain. Illustrative cases were cited which seemed to present dramatically additional supporting evidence. Finally, the author noted that lumbosacral fusions are at times followed by a recurrence of low-back pain which was found to be caused by the resultant increased stress and strain on the upper lumbar articulations consequent to the fixation of the lower segments. The author concluded that specific examination of the thoracolumbar spine should be undertaken in cases of obscure back pain when the pain occurs after spine fusion.

In discussing Dr. Macnab's paper, Dr. J. S. Barr [65] cited three patients with organic disease at the thoracolumbar junction who complained of low-back pain: The first patient had neurofibroma of the eleventh thoracic nerve root; the second had eosinophilic granuloma of the eleventh thoracic vertebra; and the third patient had tuberculosis involving the second and third lumbar vertebrae, with lumbosacral pain.

[62] Sahlgrenska Sjukhuset, Göteburg, Sweden.
[63] Duke University, Durham, North Carolina.
[64] Clair-Hill Building, 200 St. Clair Avenue West, Toronto, Ontario, Canada.
[65] 234 Marlborough Street, Boston 16, Massachusetts.

These experiences make it essential that in dealing with lumbosacral pain we must not overlook the thoracolumbar region in our physical examination or in our x-ray studies. Myelograms must include the thoracolumbar level. Dr. Barr felt that in our present state of knowledge it is not possible to localize accurately the lesion by the distribution of pain or paraesthesia; it is necessary to be very careful in interpreting the location of the source of the pain from the area of referred pain. The results of injections with novocain, locally, and hypertonic saline solution must be interpreted guardedly. The only test for mechanical strains and degenerative lesions in the thoracolumbar region that he knows is the therapeutic one; other tests lack proof of their accuracy and value.

The Study of Ground Substance in Intervertebral-Disc Degeneration. In support of the thesis that rupture of the disc is an acute phase in a chronic disorder, Dr. Barnes Woodhall [63] stated that a statistical analysis of 2,200 operative patients with ruptured discs had suggested that the protrusions had occurred in discs which were the seat of chronic degenerative disease of unknown origin. He had also reviewed 1,000 random operative patients followed between 1937 and 1953; 1,089 protrusions had been verified during 1,069 operations. There were 601 protrusions of the fifth lumbar disc, 450 of the fourth, thirty-seven of the third, and one of the first. There were only seventeen proved instances of multiple disc protrusions. There were fifty-four recurrences at the same interspace, of which nine were contralateral, and there were nine recurrences at a different interspace, making a total of sixty-three recurrences among 1,000 patients. He found an over-all clinical recurrence rate (based on "sciatica") of 8.4 per cent. Five recurrences were due to root fixation in scar; fourteen recurrences were in patients who had been treated conservatively. He reported an apparent familial tendency to disc trouble.

Speaking of the biochemical changes within the disc and their possible bearing on rupture, he said that the disc may be considered a gel composed of cell bodies and a dense collagen framework imbedded in a ground substance of salts, water, and mucopolysaccharides. The collagen component per unit of tissue volume increases with aging; the water content decreases correspondingly; and the sulphur content, considered to be present in the form of polysaccharide estrosulphate, undergoes a gradual decrease. He reviewed the two current theories: One theory postulates that chlorides pass into the nucleus pulposus, following body-fluid acidosis, displacing mucopolysaccharides and inducing degenerative changes by which the disc becomes subnormally resistant to wear and tear. The other assumes a depolymerization of the mucopolysaccharides resulting in an increase in the number of molecules, increased osmotic pressure, and increased water content. He feels that each of these hypotheses may prove to be true and that they may be complementary. In an effort to throw further light on the subject, the hyaluronic-acid content was determined in disc fragments removed at operation and in control disc tissue obtained at autopsy. In his control group, the mean content of hyaluronic acid was 47.35 milligrams per gram of wet disc. The lowest value he had obtained in eighteen control cases was 15.16 milligrams in a person with an estrogenic-hormone deficit. In fifty-one surgical specimens from fifty patients, the mean content of hyaluronic acid was 1.33 milligrams per gram. He felt the implications of his data could only be surmised at this time. The changes in hyaluronic-acid content seemed to him, however, to imply marked and permanent changes in the framework of the disc ground substance. At its inception, he thought the process might be reversible. He thought, if his data were accurate, it indicated that, when ruptured, the disc was physiologically destroyed.

Dr. J. S. Barr [65] questioned the validity of the method employed in obtaining these data. He based his questioning on the wide variation in values obtained from the autopsy material, while the variation for the ruptured disc material was much less. He did not doubt the care with which the tests had been carried out; he doubted the method, feeling that it was only roughly quantitative. He also raised the question whether the disc material removed at operation is subject to changes which might alter the hyaluronic-acid content at a rate which is different from the rate of alteration occurring in material that was removed at autopsy. He feels that Dr. Woodhall's work is of great importance and he hopes that he will pursue it further.

A Simplified Wrist Arthrodesis. An easily performed and uniformly successful wrist arthrodesis technique was described by Dr. J. Warren White [66] and Dr. Richard D. Smith [67]. A lateral incision is used. It is carried along the distal end of the radius and enters the anatomical snuff box. The tendons of the abductor pollicis longus and the extensor pollicis brevis are displaced dorsally and the distal end of the radius is exposed. The distal end of the radius is split in the transverse plane completely; the split is then continued in the carpus in line with that in the radius. The bases of the second and third metacarpals are also split in the transverse plane. A slab of the lateral cortex of the ilium of suitable dimensions is inserted into the split in the distal end of the radius, the carpus, and the bases of the metacarpals. The articular surfaces of the radiocarpal, the intercarpal, and the carpometacarpal joints are not exposed. Denuding the joints of cartilage has been found to be unnecessary. This operation has been performed in some twenty-five patients over a period of twenty years and has been found to be uniformly successful; there have been no complications.

[66] 350 South Hotel Street, Honolulu, Hawaii.
[67] Shriners' Hospital for Crippled Children, Honolulu, Hawaii.

Points brought out in the discussion by Dr. Paul C. Colonna [68] and Dr. H. Relton McCarroll [69] were the possible difficulties which might be encountered in correcting deformities at the wrist at the time of the operation. Concern was also expressed lest, in splitting the radius, damage might be done to the distal radio-ulnar joint. Anxiety was expressed that damage might be done to the dorsal branch of the radial artery in the anatomical snuff box. There seemed to be some risk of damage to the first carpometacarpal joint.

In conclusion, Dr. White pointed out that in none of his cases had there been any apparent damage to the distal radio-ulnar joint structurally or functionally and that there had been no accidents with the radial artery. He had accidentally split the distal end of the radius completely in at least half of the operations. This had had no ill effect in any instance. No patient had shown any adverse effects in the carpometacarpal joint of the thumb.

Interesting Personalities in Orthopaedics and Their Contributions to the Specialty. Dr. Leo Mayer [70] paid tribute in a most interesting way to many of the time-honored great men of orthopaedic surgery at the turn of the twentieth century. He restated Newton Shaffer's plea for a mechanical therapeutic concept of the practice of orthopaedics as opposed to Dr. Virgil Gibney's conviction that surgery must often be employed to secure satisfactory results in orthopaedic problems. In his own medical life, Dr. Mayer has witnessed many of the dramatic developments of modern medicine. He traced in his address the evolution of orthopaedic surgery from the "strap-and-buckle phase" to its present position as a major division of surgery. He emphasized that, during the years when braces were foremost on the therapeutic list, there were, nevertheless, many brilliant surgical exploits in the field of orthopaedics. In 1895 Bradford had operated successfully for recurrent dislocation of the patella. DeForest Willard was routinely performing osteotomy for the correction of rachitic deformity; Lewis Sayre, in 1854, had resected a hip joint; in 1893 his son Reginald had successfully corrected a club hand by shifting the ulna to the middle of the carpus where he achieved fusion by open operation; Dr. Harry Sherman of San Francisco had advocated early operation on the tuberculous knee and hip and had secured some good results by fusion; Gilette of Minneapolis and G. G. Davis of Philadelphia had performed open operations for non-union of the femoral neck,—they freshened the bone ends and maintained apposition with internal fixation with ivory pegs, nails, or by screws. These men worked without the benefit of an x-ray department, without transfusions, and with imperfect anaesthesia. Their success attests their extraordinary speed, dexterity, and respect for tissues. Lovett, on the other hand, was no surgeon, although his studies in pathology, his researches into the mechanics of scoliosis, his brilliance as a teacher, and his organization of the Harvard Infantile Paralysis Commission won him a high place.

During the later years of the last century, Germany and Austria held a position of leadership in medicine. Such great pathologists as Rokitansky and Virchow, such bacteriologists as Koch, Klebs, Loeffler, and Neisser, and such chemists as Ehrlich had laid a sound foundation for clinical medicine. In orthopaedic surgery, Hoffa in Berlin, Lorenz in Vienna, and Lange in Munich had gained international reputations by the time Mayer graduated from medical school. Choosing orthopaedics as his field, he went to Germany in 1912; there he worked under Lange, a great teacher, to whom he feels indebted for his training in orthopaedic fundamentals. A vivid description of the working day of that famous surgeon was given. In 1913 he was associated with Biesalski in Berlin. Here much creative work was done in tendon surgery, and the underlying principles were worked out. There was an unparalleled opportunity to gain an insight into the problems of rehabilitation, for Biesalski was one of the first in this field and devoted years of his life to the care of men handicapped by war injuries. Revealing descriptions followed of Stoffel's clinic at Mannheim, of Lorenz's work in Vienna, and of Schanz's practice in Dresden. After the First World War the great advances in bone surgery came from such general surgeons as Payr in clinical practice and Axhausen in research. The latter first observed the replacement of the dead bone of the graft by living bone, called by Phemister "creeping substitution". Payr's work on arthroplasty paved the way for Baer, Murphy, and other Americans. Lexer's studies on bone circulation then going forward have become classics. Brook's cineplastic amputation paved the way for present-day methods.

Dr. Mayer felt, however, that at that time German orthopaedic surgery was fully equaled if not surpassed by that of Italy. The leading exemplar of Italian orthopaedic surgery was Putti. A fitting tribute was paid to that great surgeon's personality, his unsurpassed knowledge and skill, his creativeness, and his varied interests. His study of the pathology of congenital hip displacements and dislocations, his development of means of early recognition and early cure by abduction, and his education of the Italian people, lay and professional, in how to deal with this prevalent Italian congenital deformity are among the great contributions of orthopaedic surgery to man's welfare.

Reference was made to Calot and Calvé who were eminent in the conservative French school of orthopaedics which held sway during the years following the First World War. Operative orthopaedic surgery developed slowly in France, and it is only lately that the French have again become active in this phase of orthopaedic treatment.

(Continued on page 1122)

[68] 3400 Spruce Street, Philadelphia 4, Pennsylvania.
[69] 3720 Washington Boulevard, St. Louis 8, Missouri.
[70] 1150 Fifth Avenue, New York 28, N. Y.

News Notes

The Annual Meeting of the **American Society for Surgery of the Hand** will be held at the Hotel Statler, Los Angeles, California, on Friday, January 28, 1955. The President of the Society for the current year is Dr. Joseph H. Boyes of Los Angeles.

The Twenty-second Annual Meeting of **The American Academy of Orthopaedic Surgeons,** under the presidency of Dr. T. Campbell Thompson of New York City, will be held at the Hotel Statler, Los Angeles, California, January 29 to February 3, 1955.

The 1955 Annual Meeting of **The American Orthopaedic Association** will be held at The Greenbrier, White Sulphur Springs, West Virginia, June 19 to 22.

The Eighth Annual Meeting of the **American Academy for Cerebral Palsy** will be held in Williamsburg, Virginia, at the Williamsburg Inn, on November 4, 5, and 6, 1954.

The Annual Convention of the **National Society for Crippled Children and Adults** will be held at the Hotel Statler, Boston, November 3 to 5, 1954.

The 1954 Meeting of the **Western Orthopedic Association** was held in San Francisco, California, October 13 to 16, under the presidency of Dr. J. Warren White of Honolulu. A complete report of the Meeting will appear in a later issue of *The Journal*.

A special scientific congress was held in New York at the College of Pharmacy, Columbia University, on October 14 and 15, which was devoted to a review of the present status of research and the treatment of critical diseases and to a forecast of future research. Six of the leading research authorities in medical and scientific fields reviewed the progress in the past decade in diagnosis and treatment. They showed how research had revolutionized therapy in their respective fields and how it had markedly decreased mortality rates from disease.

The first four volumes of **The Bulletin on Rheumatic Diseases** have been bound in soft covers and are now available to physicians.

The Bulletin, published by the Arthritis and Rheumatism Foundation, is issued nine times a year and is available without charge to all physicians and medical students who request it. Doctors wishing to receive regularly *The Bulletin on Rheumatic Diseases*, at no cost, should write to Dr. Russell L. Cecil, Medical Director, Arthritis and Rheumatism Foundation, 23 West 45th Street, New York 36, N. Y.

The bound special volume, composed of all issues of *The Bulletin* for the past four years, is available from the Arthritis and Rheumatism Foundation at the cost of $1.00.

Henry H. Kessler, M.D., Medical Director of the **Kessler Institute for Rehabilitation,** Pleasant Valley Way, West Orange, New Jersey, recently announced the establishment of a three-month residency program at the Kessler Institute.

The first month will be devoted to General Rehabilitation—Principles and Techniques. The second month will be given to Amputations of the Upper Extremity—Surgery and Prostheses, and the third month of the program will be devoted to Amputations of the Lower Extremity—Surgery and Prostheses.

Orthopaedic surgeons and residents in orthopaedic surgery who are interested in taking part in this training program should communicate with the Medical Director at the Institute for complete information.

The Sixty-first Annual Convention of the **Association of Military Surgeons of the United States** will be held November 29 and 30 and December 1, 1954, at the Hotel Statler, Washington, D. C.

The program will cover a wide range of professional and scientific subjects which should be of interest to all those engaged in military medicine and the Federal health services. The latest advances in medical and allied sciences will be shown in a large variety of technical exhibits and films.

For the entertainment of the members and guests, a full schedule of events is being arranged. As in the past, one of the outstanding features is the Honors Night Dinner on December 1 at which the Sir Henry

Wellcome Medal and Prize, the Gorgas Medal, the Stitt Award, the McLester Award, the Louis Livingston Seaman Prize, and the Founder's Medal will be presented.

The granting of credit points for retirement to eligible reserve officers for attendance at meetings is expected to be announced soon by the Department of Defense.

Orthopaedic surgeons of New England will learn with regret of the death of Norman C. Hitchcock on August 10, 1954. An amputee himself, Mr. Hitchcock was devoted to the work of rehabilitating other amputees. He first came to New England as a representative of a firm in Buffalo; he established his own business in 1899. As President of the Boston Artificial Limb Company, he has been active in the development of prostheses and in teaching fellow workers, who have since established businesses of their own. He was a charter member of the Orthopaedic Appliance and Limb Manufacturers' Association.

The Manual of Orthopaedic Surgery published by The American Orthopaedic Association with the cooperation of The American Academy of Orthopaedic Surgeons was made possible by the John R. Thompson Fund. This handbook has received enthusiastic acceptance by students, residents, and others who come in contact with orthopaedic problems. During the two years which have elapsed since publication, over 11,000 copies have been distributed.

Much interest in translations of the Manual has been expressed by Spanish, French, Portuguese, and Japanese orthopaedic surgeons.

The present Manual is distributed at cost. When it becomes self-supporting, the John R. Thompson Fund will be directed to the support of other educational activities in the field of orthopaedic surgery.

The Manual of Orthopaedic Surgery may be obtained for $1.08 per copy, with a discount of 15 per cent. for single orders of ten or more copies. Orders should be sent to the Central Office of The American Academy of Orthopaedic Surgeons, Inc., 122 South Michigan Avenue, Chicago 3, Illinois.

SIMS COMMONWEALTH TRAVELING PROFESSORSHIP FOR 1955

Dr. Robert I. Harris of Toronto, former President of The American Orthopaedic Association and former President of The Canadian Orthopaedic Association, has been appointed to one of the two Sims Commonwealth Traveling Professorships for the year 1955. Only once before has the appointment gone to one outside Great Britain and then to an Australian; and only once before to an orthopaedic surgeon, and that was to Sir Reginald Watson-Jones in 1947. It is the first time this honor has been given to a Canadian.

The appointment is to a chair established in the Royal College of Surgeons of England and heavily endowed by Sir Arthur Sims, a prominent New Zealander who is in business in England and in New Zealand. The purpose of the professorship is to facilitate the exchange of medical knowledge among the nations of the British Commonwealth. As originally planned, the endowment was to finance the cost of sending an eminent surgeon from Great Britain to the Dominions of the Commonwealth to discuss problems within his field of knowledge. The plan has since been changed. Two professors are now appointed annually—one a physician and one a surgeon; each visits half of the Commonwealth.

Dr. Harris's tour is being planned to include visits to Great Britain, Australia, and New Zealand.

The Trustees of the **Samuel D. Gross Prize** announce that essays are now being received in competition for the prize of $1,500.00.

The conditions annexed by the testator are that the prize "shall be awarded every five years to the writer of the best original essay, not exceeding one hundred and fifty printed pages, octavo, in length, illustrative of some subject in Surgical Pathology or Surgical Practice founded upon original investigations, the candidates for the prize to be American citizens".

It is expressly stipulated that the competitor who receives the prize shall publish his essay in book form, and that he shall deposit one copy of the work in the Samuel D. Gross Library of the Philadelphia Academy of Surgery, and that on the title page it shall be stated that to the writer of the essay was awarded the Samuel D. Gross Prize of the Philadelphia Academy of Surgery.

The essays, which must be written by a single author in the English language, should be sent to the Trustees of the Samuel D. Gross Prize of the Philadelphia Academy of Surgery, care of the College of Physicians, 19 South Twenty-second Street, Philadelphia, Pennsylvania, on or before January 1, 1955.

Each essay must be typewritten, distinguished by a motto, and accompanied by a sealed envelope bearing the same motto, containing the name and address of the writer. No envelope will be opened except that which accompanies the successful essay.

The Committee will return the unsuccessful essays if reclaimed by their respective writers, or their agents, within one year.

The Committee reserves the right to make no award if the essays submitted are not considered worthy of the prize.

LETTER TO THE EDITOR

The Art of Healing

To the Editor:

Many eminent diagnosticians are therapeutic nihilists. Having made a careful scientific diagnosis, based on all the available clinical and laboratory data, they relax, satisfied with the day's work, and dismiss the patient with a few words addressed to the relatives regarding the hopelessness of the prognosis. Although there are unfortunately many diseases which, in the present state of our ignorance, defy our therapeutic efforts, the wise, kindly physician will seek to allay, when he cannot cure, and will never forget that from the time of Hippocrates the great exponents of our profession have been healers. In our own orthopaedic field, Sir Robert Jones stands out as preeminent, not so much because of his scientific attainments and diagnostic skill, great though these were, but because of his healing power.

In some instances, even when one is dealing with a patient suffering from a malignant neoplasm, much can be done to lighten the way of the doomed man. Such a case was that of Mr. S. S., who consulted me because of a tumor involving the left radius and ulna with metastases to the lung. A biopsy confirmed the obvious diagnosis of a malignant osteolytic lesion, which had destroyed two thirds of the forearm bones. Fortunately, the main muscles and tendons were still intact. To lessen the intense pain and to enable the patient to continue at his work, I felt warranted in resecting the radius and ulna and replacing them by bone grafts, even though the pulmonary lesion was certain to be fatal. Sixteen months have elapsed since the operation; the lung metastases have gradually increased in size, but the patient has had no pain and has continued to earn his living.

A more striking example involves a case of progressive muscular dystrophy. I like to think of this true story as an "orthopaedic novelette".

He was eleven years old when he was brought to the Clinic of the Hospital for Joint Diseases. He was a bright little fellow, but he had to be carried into the examining room, since he was unable to stand or walk. His parents explained that at the age of four he had first shown difficulty in standing. From that time on, there had been a progressive disability. Braces had been tried but had been unsuccessful. Slowly but relentlessly the disease had run its course.

Our examination showed bilateral severe fixed equinovarus deformities with almost total paralysis of the dorsiflexors and weakness of the gastrocnemius soleus muscles. The knee and hip muscles were partially involved in the paralytic process. A biopsy confirmed the clinical diagnosis of progressive muscular dystrophy. What should be done? At the Staff Conference opinion was divided. Most of the men felt that, since progression of the disease was inevitable, the boy's admission to the Hospital would be a waste of our precious bed space, already filled to capacity. The situation, they thought, was similar to that presented by George Bernard Shaw in *The Doctor's Dilemma*. There also was a pseudohumanitarian argument: Why inflict additional suffering, the trauma of an operation, on a child who had already suffered so much? The debate, carried on, of course, in the absence of the patient and parents, became quite acrid; the protagonists of the two opposing views could not come to terms. Finally, "the chief" had to decide; for better or for worse, he advocated operative correction of the equinus deformities as the first step in the boy's rehabilitation program. The Achilles tendons were therefore lengthened and the ankles were stabilized by the Hoke method. On one side, where the tibialis anterior showed some strength, it was transplanted to the fourth metatarsal to act as an evertor. Two months later, the plaster-of-Paris dressings were removed, braces were applied, and Leonard (that was the boy's name) was transferred to the Convalescent Home at Rockaway Park. In an amazingly short period he learned to walk with the aid of crutches and began to go to school. Despite the lack of previous training, he soon became the leader in his class. A year later he had become so proficient in walking that he was able to discard braces and crutches.

At thirteen, he was graduated from grammar school and entered high school. He remained at the Convalescent Home where a zealous therapist did her best by daily exercises to slow up the spread of the paralysis. She succeeded fairly well until four years later when a drop wrist developed because of the involvement of the dorsiflexors of the right hand. Consequently, he was hospitalized again. The intact flexor carpi radialis and flexor carpi ulnaris, together with the palmaris longus, were transplanted to the paralyzed extensors, and a week later he resumed his high-school course. The operation gave him a useful hand with which he was able to write his final examination papers.

His high-school record justified his application for college. He passed the admission tests, was entered at Brooklyn College, and within a short time became one of the outstanding members of his class. However, the disease was no respector of the hallowed university halls. When eighteen, Leonard had to consult his orthopaedic advisers once more. This time, the cervical muscles were involved. Even with a collar he could not hold his head erect. So, for a third time, he entered the Hospital for Joint Diseases. The operation, a double tibial-bone graft to the cervical spine, was carried out with great difficulty because of the weakness of the

respiratory muscles. Twice during the anaesthesia he stopped breathing. Coramin had to be injected into the heart, and a blood transfusion had to be given through the saphenous vein. The result, however, was satisfactory. A month later he returned to college. When he was graduated in June 1946, he received the Gold Award, the second highest award for student activity.

He passed the Civil Service examinations and secured a job in the Statistical Department of the City of New York. Twice within the first two years he was promoted.

Some time later he again required orthopaedic advice, but this time no operation was contemplated. He consulted his doctor, accompanied by an attractive young woman who, like Leonard, had overcome the physical handicaps of an extensive paralysis, only hers was due to poliomyelitis. They wanted his medical sanction for their union. Now they are happily married.

May 28, 1954 *Leo Mayer, M.D.*

1150 Fifth Avenue

New York 28, N. Y.

LETTER TO THE EDITOR

Redistribution of Bone Salt

To the Editor:

In the June issue of *The Journal of Bone and Joint Surgery* (pages 693 to 694), Dr. Robert D. Ray makes some critical comments on my two articles on The Importance of Bone Growth as a Factor in the Redistribution of Bone Salt, published in the April issue of *The Journal*. The following is my answer to Dr. Ray's criticism:

The word "equilibrium" has been used for a time in the literature on this subject, meaning—as defined by me in one of the opening paragraphs of my first article — that the specific activity of calcium is uniform throughout the skeleton and is equal to that of the interstitial body fluid. In my investigation, I demonstrated that an equilibrium in this sense had not been reached and could not ever be reached. It should be quite clear that it is perfectly possible to discuss an equilibrium in this sense even if the specific-activity level of the body calcium constantly diminishes as a result of elimination from the body of the isotope and the ingestion of non-labeled calcium. That the term equilibrium can be used in some other sense does not throw any additional light on the present subject.

Dr. Ray presents as "inescapable" the fact that "the circulation, and hence the surface area exposed to tissue fluids, is different in the various areas of the skeleton, and diffusion of tissue fluids through the calcified matrix of bone is slow, if it occurs at all". Dr. Ray seems to believe that this fact in some way invalidates my conclusions, but he fails to explain how it does so. (Recent experiments seem to demonstrate that the opposite to this "inescapable fact" is more correct[1-4].)

Dr. Ray, in discussing the problem of redistribution, fails to mention what in his opinion is "the commonly accepted meaning of the term". A more precise definition would have been valuable.

In the case of my experiments Dr. Ray presents three points which he thinks might invalidate my conclusions.

1. If by "selective mobilization of the isotope" Dr. Ray means that the newly deposited bone salt of the metaphyseal area is reached by a removal process at a shorter interval of time after deposition than is that of the diaphyseal area, then he means exactly what my conclusions point out. I cannot agree, however, that an appreciable part of the Ca^{45} or P^{32} mobilized from the skeleton is excreted. It is well known, under normal conditions, that by far the greater fraction returns to the skeleton.

2. Dr. Ray suggests that my results have been affected by the physical displacement with growth of the metaphyseal bone into the diaphyseal region. He seems to have overlooked, however, that this possibility is excluded by the rather unusual technique employed in my experiments. I did not divide the bones through constant anatomical landmarks but through levels measured from the centers of the bones. (The

only possible error introduced might arise from the discrepancy in growth in length between the proximal and the distal ends of the same bone. This error is slight and of course not to the advantage of the conclusions drawn in my paper.)

3. Dr. Ray believes that the specific-activity ratio of the ends to the shafts is affected by "dilution of the isotope with the deposition of new matrix in the area". It seems that he has reached this belief by the processes of logic: "a changing ratio may indicate a change in either the denominator, the numerator, or both". Dr. Ray's belief, however, is ruled out by the mere fact that, when the bones are divided into ends and shafts, there does not occur any marked change with time in the ash-weight ratio of the ends to the shafts. From Table I-A in my first paper, it is indeed seen that the ash-weight ratios of Piece 1 and Piece 2 do not show any significant change at all during the period of three to sixty-seven days following the start of the experiment. During the same period of time, the specific-activity ratio rose from .32 to 2.1. The change was thus brought about almost exclusively by a change in activity.

According to Dr. Ray, the technique of pooling the bone samples makes statistical analysis extremely difficult, if not impossible. This is not correct; for it is well known that a curve can be analyzed statistically even if each point of the curve is based on one single determination. Since the curves under discussion have a fairly simple course, any reader with some knowledge of statistics can ascertain whether or not my conclusions are valid from a statistical point of view. The reason no statistical data concerning these curves have been submitted is that the experimental findings on which my conclusions are based are so obvious that, according to my view, a detailed statistical evaluation is unnecessary.

I cannot agree with Dr. Ray that the radio-autographic technique is preferable to the quantitative employment of isotopes when investigating problems in this sphere. The principal advantage of radio-autograms seems to be that they are easier to understand than are tables and curves derived from a quantitative isotope experiment. This advantage seems to be slight, compared with the advantage of the detailed analysis which is made possible only by a quantitative experiment. Dr. Ray's presentation of the experiment by Dr. Aub seems to demonstrate one of the pitfalls of the morphological method: If alizarin is deposited along with bone formation (and there seems to be general conviction on this point), then the logical conclusion would be that bone formation is inhibited in the shafts but not in the ends after alizarin administration. A more reasonable interpretation of this experiment is that, because of the slow rate of bone formation in the shafts, it takes some time after alizarin administration for enough alizarin to be deposited in the shafts to be demonstrable even there! At this time a great part of the alizarin originally deposited in the metaphyseal area must have been removed and redeposited in new locations in the shafts *and* in the metaphyseal area. However, the radio-autographic technique seems to have advantages over the alizarin technique. The reader is referred to the investigations by Leblond, Wilkinson, Bélanger, and Robichon and by Tomlin, Henry, and Kon, which demonstrate serial radio-autographs, a kind of investigation which Dr. Ray asks for. As yet we have, however, no reliable method for quantitative evaluation of the radio-autographic image. *This can only be brought about by methods similar to the one I have employed.*

September 1, 1954 *Göran C. H. Bauer*
Department of Pharmacology,
University of Lund,
Lund, Sweden

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Book Reviews

THE KNEE AND RELATED STRUCTURES. Injuries, Deformities, Diseases, Disabilities. Philip Lewin, M.D., F.A.C.S., F.I.C.S. Philadelphia, Lea & Febiger, 1952. $16.00.

Dr. Philip Lewin has set himself a difficult goal in the introduction to his comprehensive *The Knee and Related Structures* when he states "Little can be said about the knee that has not already been said . . . However, one can now find it all in one volume, digested, correlated, integrated and evaluated."

He proceeds, chapter by chapter, to give a very inclusive review of the current knowledge and oftentimes conflicting views of various authorities. In most instances, he sums up these views and adds bits of his own knowledge gained through extensive reading and through many years of experience as a busy orthopaedic surgeon. While this may be somewhat confusing in certain areas, the sum total is quite understandable. The author has many firm convictions which are expressed in epigrams and aphorisms, many of which are apt and to the point. His analogies are perhaps more directed to the layman than to the physician, but they do serve to drive home his point. For example, the author compares the roentgenogram of the upper end of the tibia in a child to a frosted layer cake. With the author's positive approach, it is inevitable that many expressions of opinion appear as statements of fact; this may cause an occasional eyebrow to be lifted.

Certain sections of the book are outstanding. Of especial value is the chapter on history and examination, including a very detailed and valuable section on the significance of laboratory procedures. The chapters on apparatus, on surgical preparation, and on operating technique merit study. Rehabilitation is well presented, the author using such signs and mottoes as "Have you exercised your quad today?" and "Force the patient but not the joint" to advantage.

The chapters covering strain, sprain, and intrinsic injury are very well done. Especially readable is the description of chondromalacia and chondritis. Pyogenic, tuberculous, luetic, and fungoid infections are all well described and illustrated. The descriptions of neoplasms are unusually comprehensive and clear.

The sections dealing with fractures might well have been omitted since only a very brief discussion is possible; this subject is better presented elsewhere. However, the material given is sound, if not all-inclusive.

Some of the material seems hardly appropriate in a volume restricted to the knee. Particularly is this true of the chapters "Operations for the Residual Effects of Anterior Poliomyelitis", "Spastic Paralysis, Involving the Knee", "Circulatory and Vascular Disturbances of the Knee", and "Equalization of Length of Lower Extremities", since all of these are major subjects in themselves and are in no way peculiar to the knee joint. Space does not allow the author to do justice to these subjects, and they seem hastily and poorly presented compared with other reports on these same subjects.

The book is well documented, and the author has given an imposing array of references. He scrupulously tries to give credit where it is due and often presents diametrically opposite views about the same condition, each properly annotated. He decides the issue rather dogmatically, however, and one is inclined at times not to agree.

For one who has known the author, to read this book is to enjoy again the analytical mind, keen insight, and firm convictions which have characterized his speech and writings. The book is well worth while, both for the orthopaedist and his surgical colleagues. It is well bound, well printed on excellent paper, and beautifully illustrated.

Don H. O'Donoghue, M.D.

PATHOLOGIE DU PIED. Physiologie—Clinique. Traitement Médical, Orthopédique et Chirurgical. Jean Lelièvre. Paris, Masson et Cie, 1952. 4500 Fr.

A review of a number of unsatisfactory postoperative results obtained in spite of the meticulous adherence to known and accepted techniques compelled the author to re-investigate prevailing physiological principles and methods.

Pathologie du Pied is the result of this effort. It is a large volume of 585 pages, with a fairly good index and a limited bibliography. There are 518 illustrations, mostly line drawings, some of which are exquisite.

The author has attempted to include all possible material in covering the large field of conditions affecting the foot. The table of contents reveals the wide scope of the text. There are eight main divisions. In the first division, all the basic elements are included (the architecture, statics and dynamics of the foot, the principles of shoe construction and wear, and prostheses). Descriptive anatomy is fortunately omitted, because in most similar texts it is not contributory and, in the reviewer's opinion, simply reproduces illustrations and descriptions from well known textbooks of anatomy.

In the second division, there is a fairly extensive review of congenital deformities, as well as the methods

of treatment. The paralytic foot, caused by various conditions, and the treatment thereof form the third division. The fourth division on traumatic lesions deals with all the osseous and soft-tissue structures and includes an excellent short review of amputations. The fifth division describes the large group of acquired osteo-arthritic lesions, arthropathies, tumors, and growth disturbances. Apparently the author did not encounter any cases of osteoid osteoma, for this condition is not mentioned.

The sixth division is devoted to tuberculosis and common infections of the osteo-articular structures, and the seventh division considers all soft-tissue lesions. It is of interest to note that the contracture of the plantar aponeurosis, frequently called Dupuytren's contracture of the plantar aponeurosis, is described by the author as Ledderhose's disease.

The eighth and last division is devoted to the subject of surgical technique. Throughout the text the author emphasizes the normal function and physiopathology of the muscles of the foot and ankle. It is remarkable, however, how comparatively little can be added to the magnificent findings of Duchenne of Boulogne.

There is an excellent, although simplified, analysis of normal and pathological gait presented in a series of simple drawings. The frequently encountered lengthy descriptions which are difficult to follow are here avoided.

The book is almost encyclopaedic in character. Certain parts, therefore, are somewhat less than complete, while others are quite ample and excellent, as exemplified by the chapter on hallux valgus and on surgical technique. The book is written from the standpoint of physiopathology, and some of the author's ideas are difficult to accept. Many of the operative procedures introduced by American orthopaedic surgeons are concisely and explicitly described as such. Other familiar procedures bear names which differ from the names known to American orthopaedic surgeons.

Pathologie du Pied is a carefully written and useful book which will contribute greatly to the understanding and improvement of surgery of the foot.

Emanuel B. Kaplan, M.D.

La Spondyloarthrite Ankylosante. Clinique, Radiologie, Anatomie Pathologique, Traitement. J. Forestier, F. Jacqueline, et J. Rotes-Querol. Paris, Masson et Cie, 1951. 2650 Fr.

The senior author is well known for his work on ankylosing spondylitis. The text is based on extensive experience. About 400 cases have been collected by the authors. A number of these cases were observed personally by the senior author over many years, and definite conclusions were drawn concerning the nature of the disease and its evolution with and without treatment.

A concise historical review traces the first description of the disease to an Irish observer, B. Connor, who made a report on the pathology in a thesis to the Faculty of Rheims in 1691. Salient dates in the development of treatment and ideas on pathogenesis are given.

La Spondyloarthrite Ankylosante is a book of 312 pages with well reproduced roentgenograms and other illustrations (total of 143) and a bibliography of 221 items. It represents a well balanced study of the subject with a number of pertinent illustrative case reports.

In its clear and concise presentation nothing of importance has been omitted. The essential anatomy, in relation to gross and microscopic pathology, roentgenographic data, and a lucid clinical analysis of the affliction with its modalities are well presented.

The distinct, specific characteristics of the condition in contrast to other rheumatic manifestations are brought out. The importance of those characteristics which influence the end results of surgical treatment is very well shown. A good review of the results obtained by conservative and operative orthopaedic methods is presented. Other methods of treatment, based on personal experience and on the experiences of others, are impartially described in detail. The added importance of hygienic and rehabilitative measures is emphasized.

This book is of value. It may help the orthopaedic surgeon to obtain a better conception of the pathogenesis, as well as to help him to eliminate cases which are foredoomed to failure from surgical intervention. It may help all those who are engaged in the treatment of rheumatic diseases by bringing about a better understanding of ankylosing spondylitis as a distinct entity. It will help many by promoting cooperation between the orthopaedic surgeon, rheumatologist, and all who are interested in rehabilitation.

Emanuel B. Kaplan, M.D.

Die Angiographie zur Erkennung, Behandlung und Begutachtung peripherer Durchblutungsstörungen. Dr. med. habil. H. W. Passler. Stuttgart, Georg Thieme Verlag, 1952. DM. 29.70.

Through the very liberal use of reproductions of x-rays, this book is an atlas of angiography in normal states and in a wide variety of diseases, both of the arteries and of the veins. Sections are devoted to the clinical pictures seen in the functional blood-vessel diseases and the organic arterial disorders of endarteritis obliterans, arteriosclerosis, atherosclerosis, and Buerger's disease. The various techniques of investigating these arterial diseases are discussed, and the technique of visualization of the arterial system in these various

conditions in all locations is completely described. In the course of dealing with the clinical and pathological discussions of organic diseases of the arteries, arteriograms are used to illustrate the conditions. The reproductions of the arteriograms are extremely well done, apparently without retouching. This adds materially to the value of the work. In his presentation of techniques of arteriography, the author describes a simple cassette, divided into three portions, which he devised for taking serial pictures. Many photographs are used in the section on technique to illustrate the instruments and needles used, the cassette, the position of the table, and the method of injection. In the section on aortography, the author describes an apparatus designed by him which, through the use of gas pressure, provides for very rapid injection of the contrast medium. A normal aortogram, one in arteriosclerosis obliterans, and one demonstrating a large renal tumor are presented. The dangers of extravasation of the dye outside the blood vessel are discussed, and certain methods of treatment are presented.

A chapter is devoted to the conservative, as well as to the surgical, handling of peripheral-arterial disease, including sympathetic blocks, sympathectomy, and clinical management.

Venography is considered rather briefly, but there is a good demonstration of venography of the lower extremity by means of the injection of the contrast medium into the body of the calcaneus. The technique for this method is given.

The bibliography is not by any means confined to articles on the roentgenographic demonstration of vessels, but includes articles dealing with clinical descriptions of cases and pathological conditions.

In general, although the work contains a good deal of information and text relating to the pathology, clinical picture, and general treatment of peripheral-arterial disease, its principal interest is in its portrayal of the technique and of the results from visualization of the arteries and veins. Its brevity, combined with broad coverage, makes it of interest to anyone in general medicine and surgery who is able to read German. The technical portions are of great value to those whose interest lies in the diagnosis and treatment of vascular conditions.

Ormand C. Julian, M.D.

HUMAN EMBRYOLOGY. Ed. 2. Bradley M. Patten, Ph.D. New York, The Blakiston Company, 1953. $12.00.

The author has added many new illustrations to the Second Edition of this popular book. He has also added considerable new material on the younger human embryos and has removed much of the material dealing with the younger monkey embryos. The text is written in a style which has characterized his other books. The reader is pleasantly surprised by a text which is accurate and, at the same time, interesting and easily followed. Students at all levels will find that the task of learning has been greatly eased by the artistry of the author. This book should be highly recommended to beginning students and to busy physicians and surgeons who either want to look up isolated details or to review completely at a minimum cost of time.

J. E. Markee, Ph.D.

FUNDAMENTALS OF CLINICAL ORTHOPEDICS. Peter A. Casagrande, M.D., and Harold M. Frost, Jr., M.D. New York, Grune & Stratton, 1953. $18.50.

The most remarkable characteristic of this book is its inclusiveness. There is some discussion in it of nearly every aspect of disorders of the musculoskeletal system, together with some discussion of the system's normal function. All this, adequately illustrated and well indexed, has been fitted handily into 582 pages of easily readable print.

As a general pattern, each clinical entity is described separately in terms of etiology, clinical aspects, and treatment. Nothing is seemingly missed; every tumor, every fracture, and every infection, congenital anomaly, strain, sprain, and bursal disorder is discussed. Diverse topics of a nature more general, such as casts, other splints, limps, anaesthesia, bone metabolism, neurophysiology, and bacteriology are also discussed in one place or another.

In their effort to extract from the vast mass of available information the minimum essential to allow a reader a fair understanding of any aspect of the whole field of orthopaedic interests, the authors have been able editors, summarizing widely accepted current concepts and describing as accredited treatment conservative and sensible methods.

The physician practising other than orthopaedic surgery will find it the most useful book written about orthopaedics,—an up-to-date and careful reference book. Very likely undergraduate students will prefer it as their text in orthopaedics; certainly it is a most convenient source of information.

In order to provide the convenience of an all-encompassing volume, it is necessary to exclude the history of developments in the field, the close integration of the "laboratory" sciences with specific clinical diseases in the many instances when this might be accomplished, and the consideration of present efforts to solve some of the many problems which exist,—embellishments of medical literature which not only lend dramatic interest but also lead to a fuller understanding of a subject new to the reader.

To the orthopaedic surgeon this book can serve much as a good dictionary serves a writer,—as a source of information concerning many subjects (some obscure) with which he very likely feels he is familiar but

about which he requires some reassurance. The complete lack of bibliography diminishes the value of this work as a reference text.

It need not be said that this book is not an atlas of surgical procedures or that it is not the place to look for the authors' newest and most original ideas concerning any particular problem. One book cannot be all things, and the authors have not intended that this should be. They have accomplished their aim of providing in one volume a survey of a huge subject, and the survey is excellent.

William N. Jones, M.D.

THE FOOT. Ed. 4. Norman C. Lake, M.D., M.S., D.Sc.(Lond.), F.R.C.S.(Eng.). London, Baillière, Tindall and Cox, 25 shillings; Baltimore, The Williams & Wilkins Co., 1952. $5.50.

In his preface to this Fourth Edition, the author quotes from the preface of the First Edition the statement of its aim,—"to deal with those conditions which come within the purview of the practitioner and general surgeon, omitting major orthopaedic procedures, and to provide a volume which will be of value to the Chiropodist, Physiotherapist and other Medical Auxiliaries, even though its scope is beyond the requirements of those undertaking these ancillary services".

Clearly the book was not designed to instruct in orthopaedic surgery, and the chapters concerned with clinical matters (which are the larger portion of the book) will appear to the orthopaedic surgeon as undetailed discussions of subjects with which he is perfectly familiar.

The first two chapters are concerned with the evolution of the human foot, the fourth discusses the development of footwear, and in the eleventh the author argues his belief that architectural factors (bone contour and ligaments) are more important to the existence of foot arches than are physiological forces of the postural tone of the muscles. These chapters all reflect the author's experience and intense interest in his subject and are most engaging reading for the orthopaedic surgeon.

William N. Jones, M.D.

BOOKS RECEIVED

The receipt of the following books is acknowledged; such a notice may be regarded as recognition of the courtesy of the sender.

GERIATRIC MEDICINE. Medical Care of Later Maturity. Ed. 3. Edited by Edward J. Stieglitz, M.S., M.D., F.A.C.P. Philadelphia, J. B. Lippincott Company, 1954. $15.00.

MEDICAL PROGRESS, 1954. A Review of Medical Advances During 1953. Edited by Morris Fishbein, M.D. New York, The Blakiston Company, Inc., 1954. $5.00.

PHYSICAL EXAMINATION OF THE SURGICAL PATIENT. J. Englebert Dunphy, M.D., F.A.C.S., and Thomas W. Botsford, M.D., F.A.C.S. Philadelphia, W. B. Saunders Company, 1953. $7.50.

THE SURGERY OF INFANCY AND CHILDHOOD. Its Principles and Techniques. Robert E. Gross, M.D., D.Sc. Philadelphia, W. B. Saunders Company, 1953. $16.00.

THORACIC SURGERY. Ed. 2. Richard H. Sweet, M.D. Philadelphia, W. B. Saunders Company, 1954.

PROCEEDINGS

(*Continued from page 1113*)

In writing of the great Sir Robert Jones, the author quoted tributes from Lord Moynihan, Ridlon, Packard, William Mayo, and Goldthwait.

Back in the United States the young orthopaedic surgeon found himself in the midst of far-reaching developments. Albee and Hibbs and their respective procedures to secure spine fusion for the arrest of tuberculosis of the vertebral bodies had opened up a new vista. Both techniques were published in 1911. Albee was amazingly adept with instruments; Hibbs was a surgeon of great ingenuity. A fitting tribute was paid to these two dynamic personalities.

Royal Whitman, a good surgeon and an outstanding teacher, is remembered for a number of operative procedures which are now no longer extensively used. It seems hardly fair to his memory to consider the abduction plaster-of-Paris spica dressing used in fractures of the femoral neck as his main contribution; this method of treatment is nevertheless a milestone in the progress of treatment of intracapsular fractures of the femoral neck.

Goldthwait, Brackett, Baer of the Johns Hopkins School, Hoke, Ridlon, Porter, Campbell, Starr, Gillette, and others made outstanding contributions to the development and advancement of orthopaedic surgery in America, but limitations of space make it hardly possible to give them full credit.

The address was an interesting record of the author's experiences and impressions. It is a valuable fragment of the history of orthopaedic surgery. All these men greatly interested and perhaps profoundly influenced him and it is only fitting and proper that tribute should be paid to them.

Acknowledgments

The Journal of Bone and Joint Surgery wishes to acknowledge with thanks the receipt of the following publications sent to the Editorial Office:

Acta Chirurgiae Orthopaedicae et Traumatologiae Čechoslovaca (Praha), **21:** 3, 1954.
Acta Chirurgica Belgica (Bruxelles), **53:** No. 4, 1954.
Acta Medica et Biologica (Niigata, Japan), **1:** Nos. 1, 2, 1953.
The American Heart (American Heart Association), **4:** 2, 1954.
Anales del Servicio de Traumatología del Dr. López-Trigo (Valencia), **8:** Núm. 4, 1953.
Archiv für Japanische Chirurgie (Kyoto), 22. Band, 6. Heft, 1953; 23. Band, 1. Heft, 1954.
Archivos de la Sociedad de Cirujanos de Chile (Santiago de Chile), **5:** Núm. 4, 1953.
Boletín del Instituto de Patología Médica (Madrid), **9:** Núms. 4, 6, 1954.
Boletines de la Sociedad de Cirugía de Rosario (Rosario, Argentina), **20:** Nos. 1–2, 7–8, 1953; **21:** Nos. 1, 2, 1954.
Boletines y Trabajos de la Sociedad Argentina de Ortopedia y Traumatologia (Buenos Aires), **29:** No. 2, 1954.
Bollettino di Oncologia (Roma), **28:** N. 1, 1954.
The Bulletin of The Biological Sciences Foundation, Ltd. (Washington, D. C.), **1:** No. 4, 1954.
Bulletin of the National Society for Crippled Children and Adults, Inc. (Chicago), **17:** Nos. 3–4, 5, 1954.
Bulletins et Mémoires de l'École Préparatoire de Médicine et de Pharmacie de Dakar (Dakar, French West Africa), **1:** 1952–1953.
Cleveland Clinic Quarterly (Cleveland), **21:** No. 3, 1954.
Cirugía, Ginecología y Urología (Madrid), **7:** Núms. 3, 4, 1954.
The Crippled Child (The National Society of Crippled and Adults, Inc., Chicago), **32:** Nos. 1, 2, 1954.
The Gunma Journal of Medical Sciences (Maebashi, Japan), **2:** No. 4, 1953.
Harper Hospital Bulletin (Detroit), **12:** Nos. 3, 4, 1954.
Hospital de Cirurgia Boletim do Centro de Estudos (Aracaju, Sergipe, Brazil), **1:** Nos. 5, 6, 1953.
Hospital for Joint Diseases, 47th Annual Report, for the Year Nineteen Fifty-three. New York City.
Indice Bibliografico Oncologico della Lega Italiana per la lotta contro i Tumori (Roma), **1:** N. 1, 2, 1954.
Journal of the Indian Medical Profession (Bombay), **1:** No. 4, 1954.
The Journal of the Osaka City Medical Center (Osaka, Japan), **2:** Nos. 2, 3, 4, 1953.
The Keio Journal of Medicine (Tokyo), **2:** No. 1 & 2, 1953.
The Kumamoto Medical Journal (Kumamoto, Japan), **5:** Nos. 3–4, 1953; **6:** Nos. 1, 2, 1953.
The Kurume Medical Journal (Kurume-Shi, Japan), **1:** No. 1, 1954.
Kyushu Memoirs of Medical Sciences (Fukuoka, Japan), **3:** No. 3, 1953; **4:** No. 1, 1953.
Médica (Matanzas, Cuba), **13:** Núms. 1, 2, 3, 1954.
Medical Journal of Osaka University (Osaka, Japan), **4:** No. 2–3, 1953; **5:** No. 1, 1954.
The Nagoya Journal of Medical Science (Nagoya, Japan), **16:** Nos. 2, 3, 1953.
Nagoya Medical Journal (Nagoya, Japan), **1:** No. 4, 1953.
Osaka Daigaku Igaku Zassi (Osaka, Japan), **6:** No. 3, 1954.
PB — Physician's Bulletin (Lilly), **19:** No. 8, 1954.
Protección Social (La Paz), **16:** 191–192, 1954.
The Red Cross World (Geneva), **35:** Nos. 1, 2, 1954.
Revista del Colegio Médico (Cienfuegos, Cuba), **4:** Nums. 3, 4, 1953.
Revista Médica Municipal (Rio de Janeiro), **17:** Núm. 2, 1953.
Sanidad *y* Beneficencia Municipal (Habana), **13:** Nums. 2, 3 y 4, 1953.
Sociedad de Cirugía de Córdoba Boletines y Trabajos (Córdoba, Argentina), **14:** Nros. 8–9–10, 11–12–13, 1953.
Sociedad de Cirujanos de Chile, Noveno Congreso Interamericano y Vigesimoseptimo Chileno de Cirugia (Santiago de Chile), Fasc. II, 1954.
University of Chicago. Announcements. The School of Medicine. For Sessions of 1954–1955.
Villaclara Medica (Santa Clara, Cuba), **22:** Num. 6, 1952.
World Medical Journal (New York City), **1:** Nos. 3, 5, 1954.
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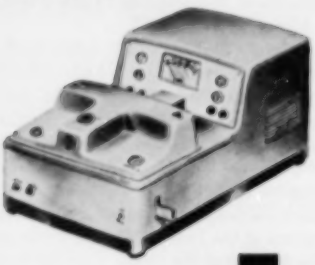

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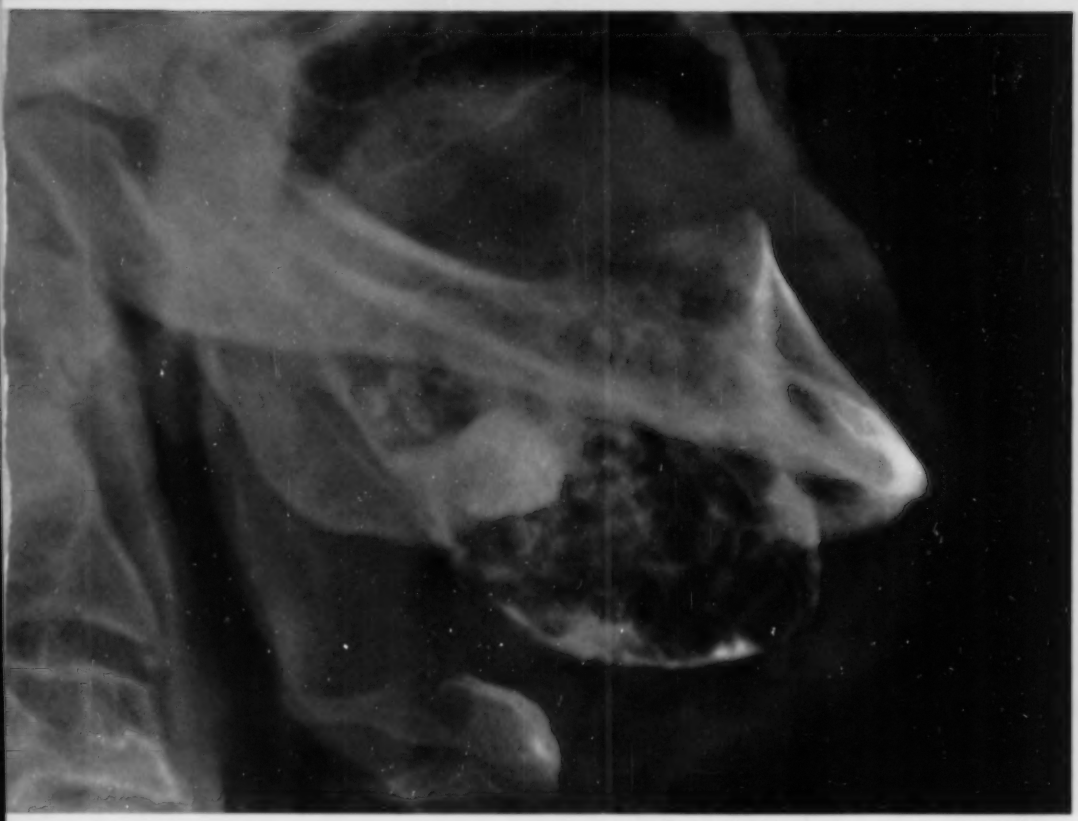

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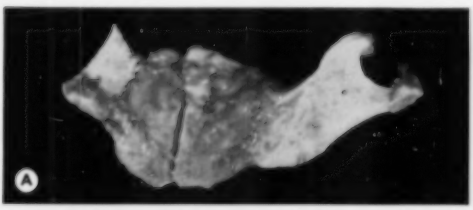

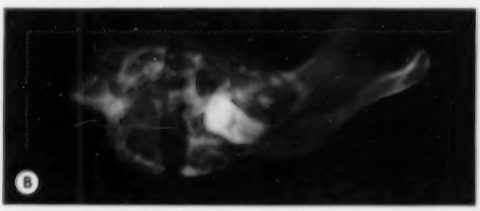

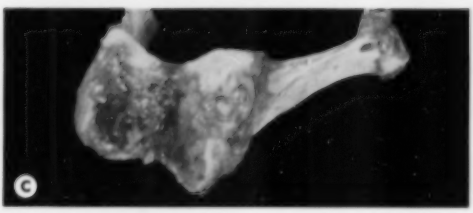

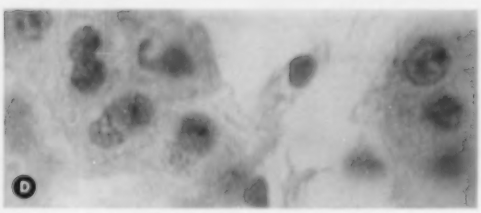

A. Photograph of resected mandible.

B. Radiograph of resected mandible.

C. Photograph of resected mandible cut to show appearance of cross section.

D. Photomicrograph (×1000) of resected mandible.

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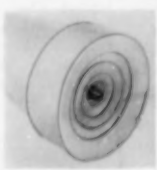

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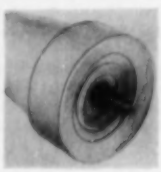

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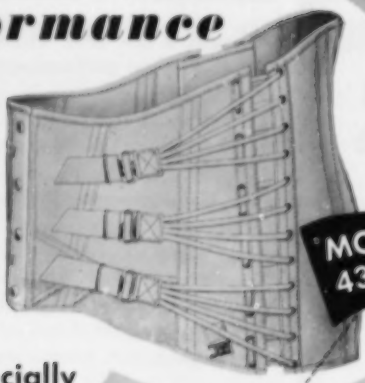

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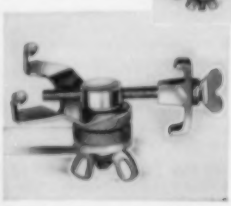

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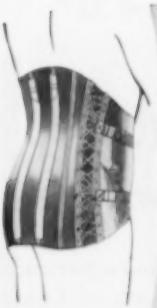

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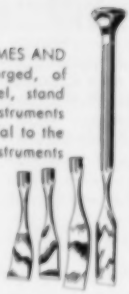

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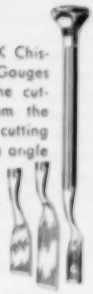

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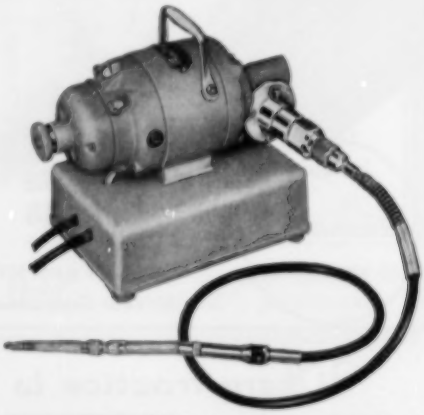

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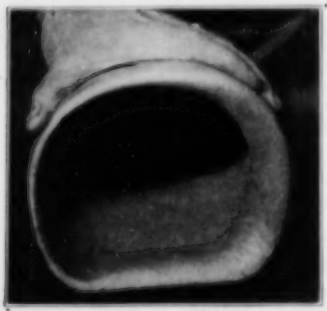

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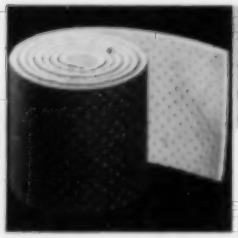

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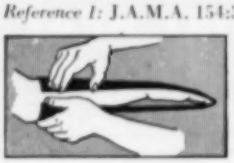

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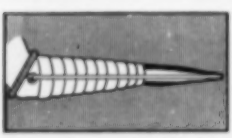

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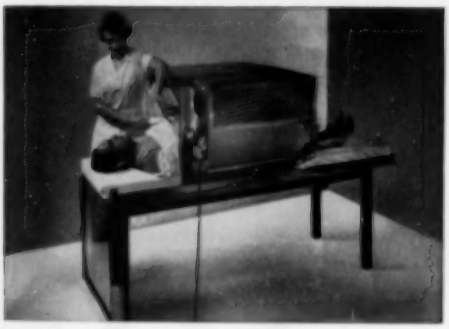

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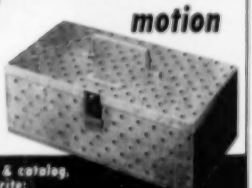

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